
Healthcare Cyber-Physical System - Pandemic Era Perspectives

**Keynote – International E-Conference on Advances in
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Outline

- Healthcare → Smart Healthcare
- Smart Healthcare - Characteristics
- Smart Healthcare - Components
- Smart Healthcare - Examples
- Smart Healthcare – Challenges
- Smart Healthcare – Solutions of Challenges
- Smart Healthcare – COVID-19 Perspectives
- Conclusions and Future Directions

Healthcare to Smart Healthcare

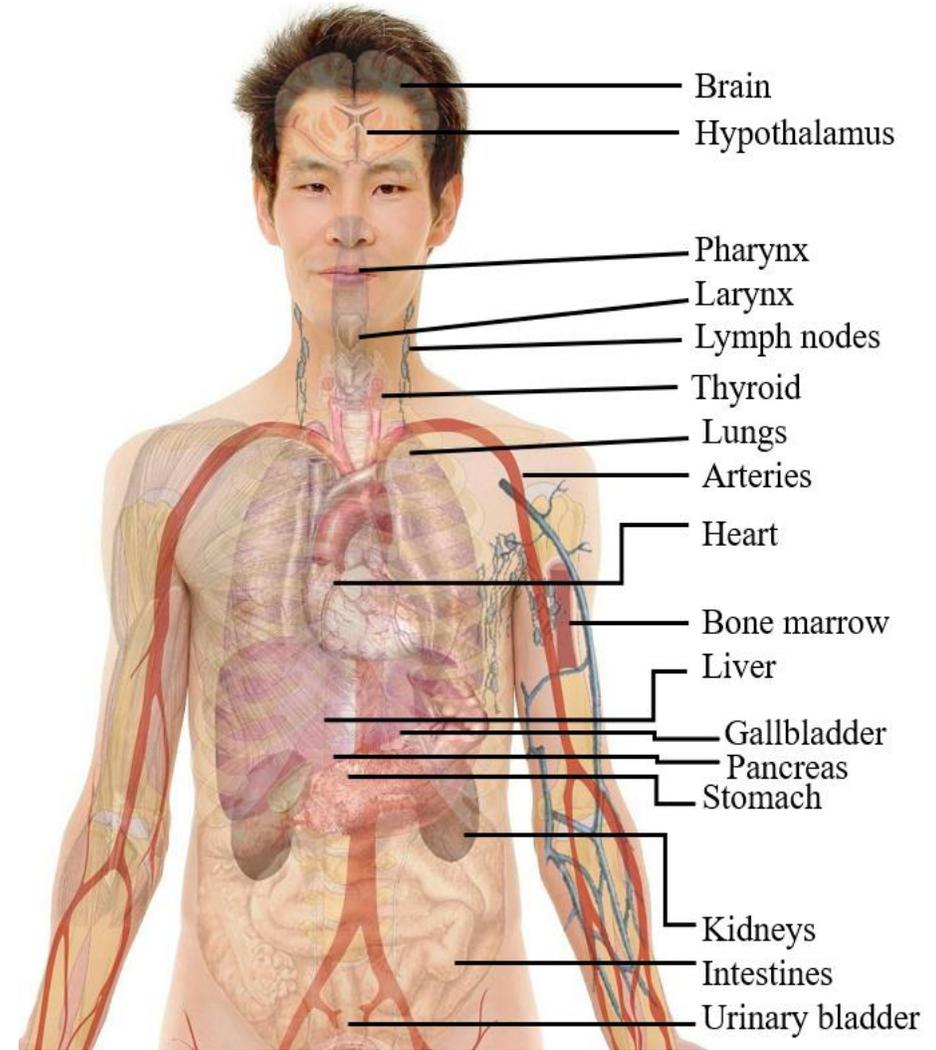
Human Body and Health

Human Body

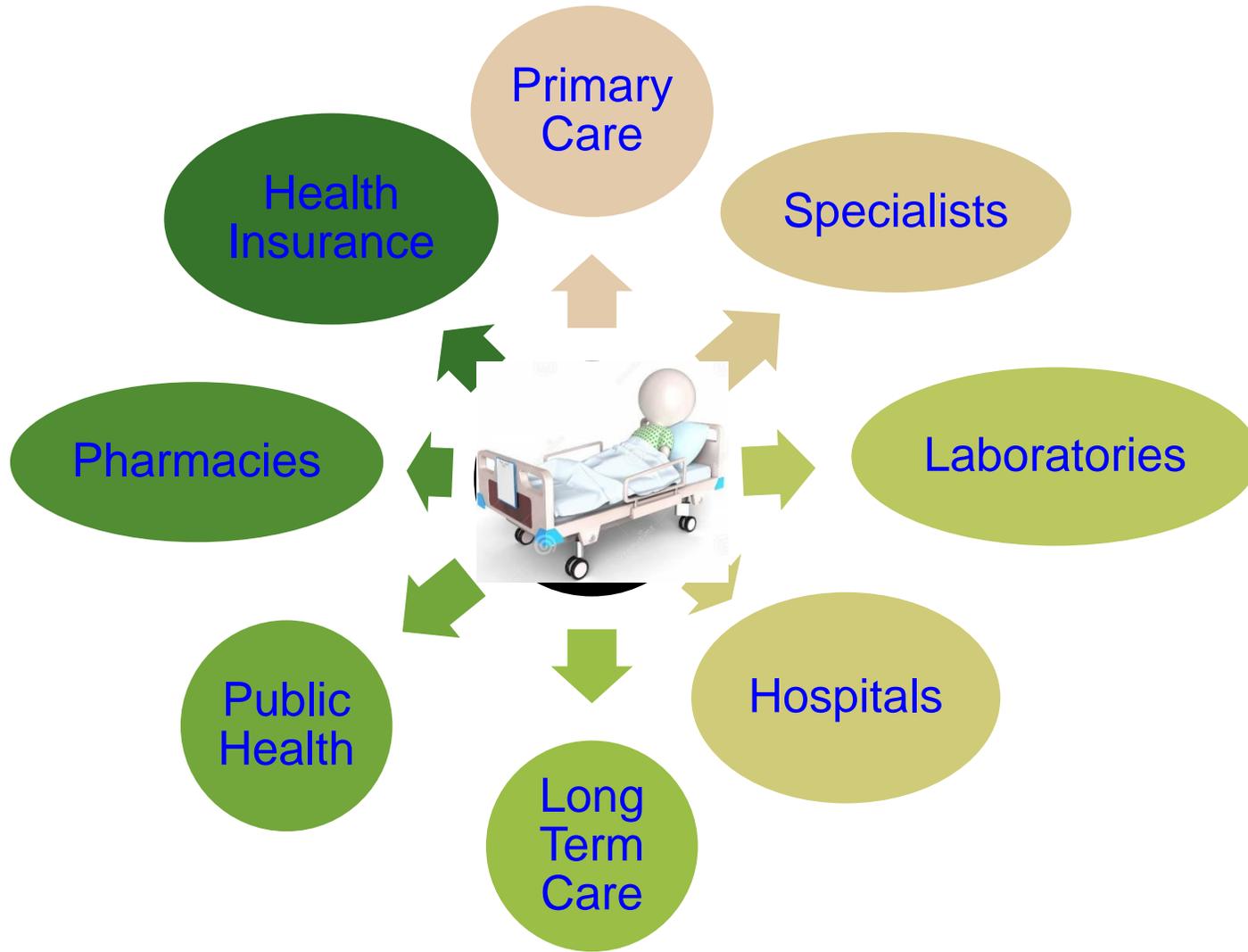
- From an engineering perspective, the human body can be defined as a combination of multi-disciplinary subsystems (electrical, mechanical, chemical ...).

Health

- Human health is a state of complete physical, mental and social well-being.



Traditional Healthcare



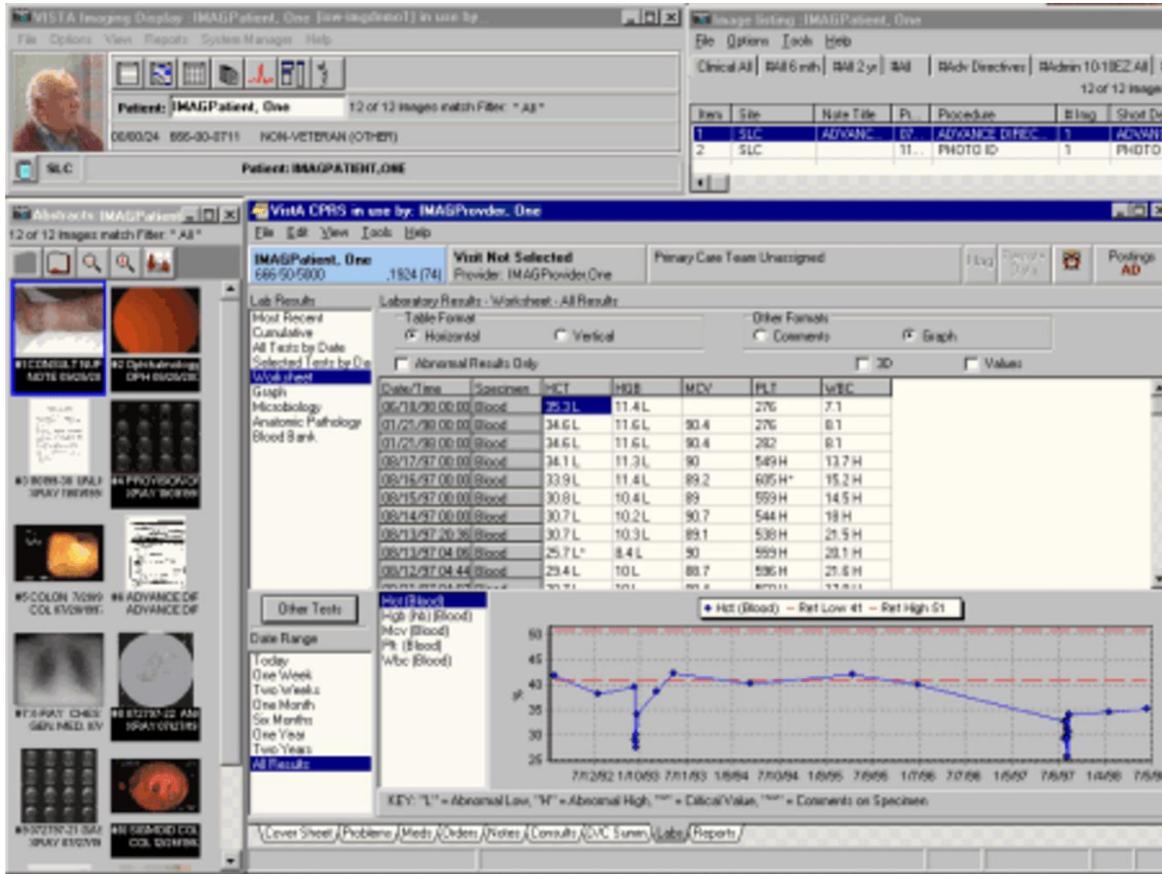
- Physical presence needed
- Deals with many stakeholders
- Stakeholders may not interact
- May not be personalized
- Not much active feedback
- Less effective follow-up from physicians

Telemedicine



Telemedicine: The use of telecommunication and information technology to provide clinical health care from a distance.

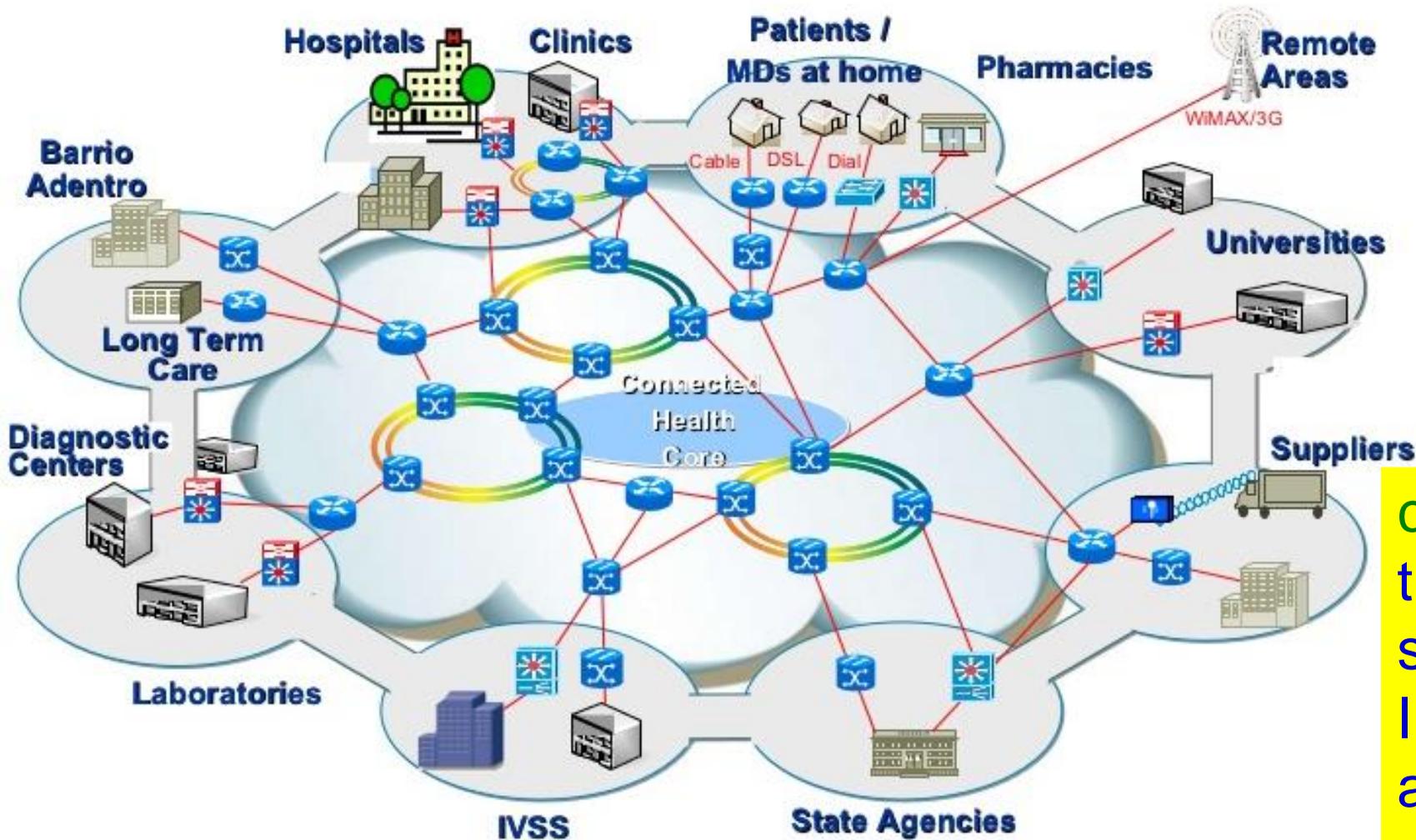
Electronic Health (eHealth)



eHealth: The use of information technology to improve healthcare services.

Source: W. O. Nijeweme-d'Hollosy, L. van Velsen, M. Huygens and H. Hermens, "Requirements for and Barriers towards Interoperable eHealth Technology in Primary Care," *IEEE Internet Computing*, vol. 19, no. 4, pp. 10-19, July-Aug. 2015.

Connected Health (cHealth)



Source: https://www.slideshare.net/tibisay_hernandez/connected-health-venfinal

cHealth: Connections of the various healthcare stakeholders through Internet to share appropriate data to better serve the patients.

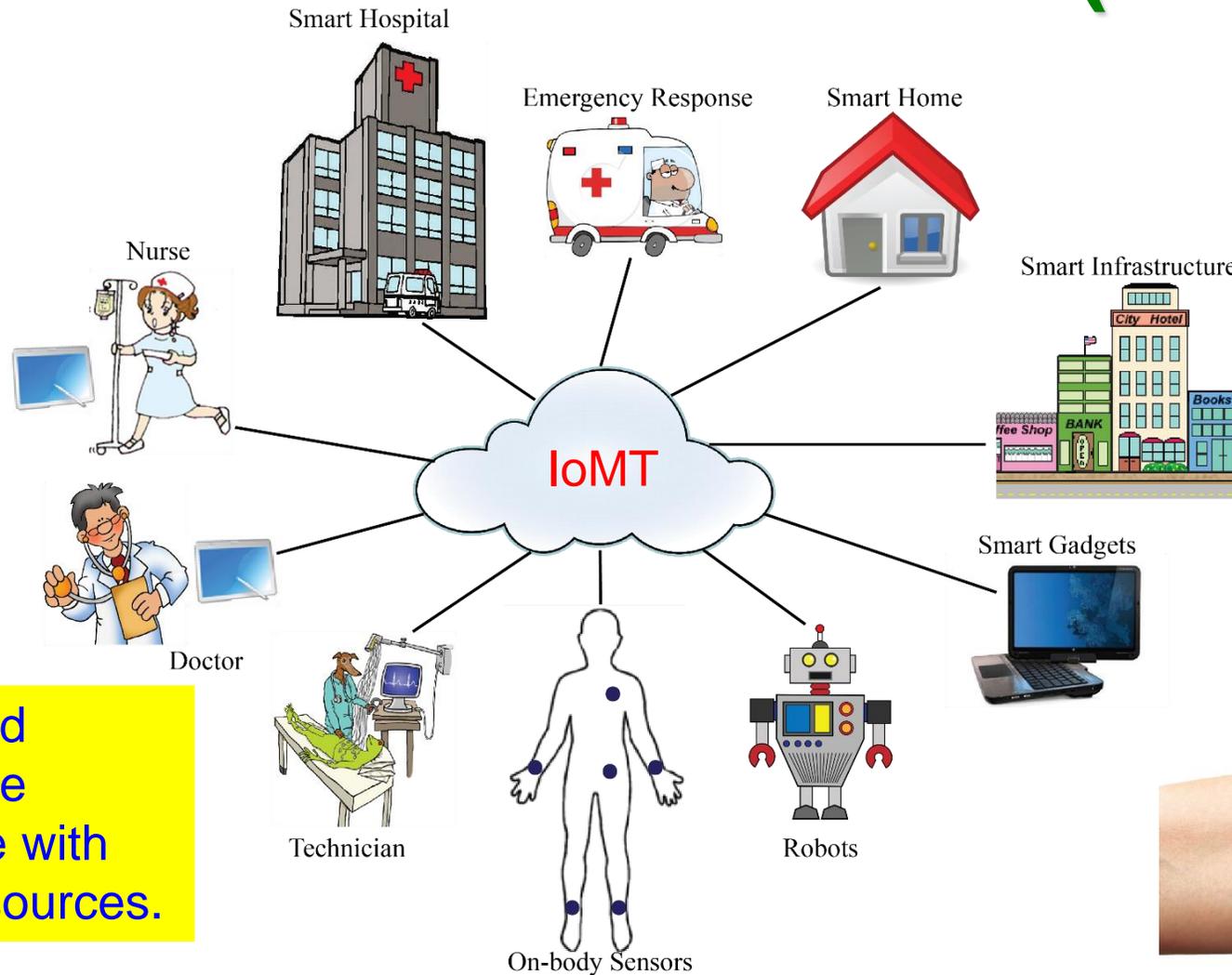
Mobile Health (mHealth)



mHealth: Healthcare supported by *mobile devices* that uses mobile telecommunications and multimedia technologies for the delivery of healthcare services and health information.

Source: H. Zhu, C. K. Wu, C. H. KOO, Y. T. Tsang, Y.Liu, H. R. Chi, and K. F. Tsang, "Smart Healthcare in the Era of Internet-of-Things", *IEEE Consumer Electronics Magazine*, vol. 8, no. 5, pp. 26-30, Sep 2019.

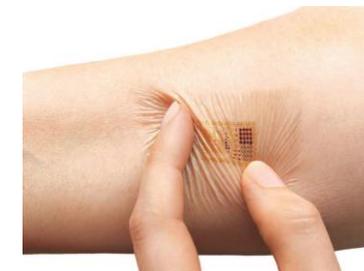
Smart Healthcare (sHealth)



Fitness Trackers



Headband with Embedded Neurosensors



Embedded Skin Patches

Quality and sustainable healthcare with limited resources.

Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 7, Issue 1, January 2018, pp. 18-28.

Smart Healthcare - Characteristics

What is Smart Healthcare?

Smart Healthcare ←
Conventional Healthcare
+ Body sensors
+ Smart Technologies
+ Information & Communication Technology (ICT)
+ AI/ML

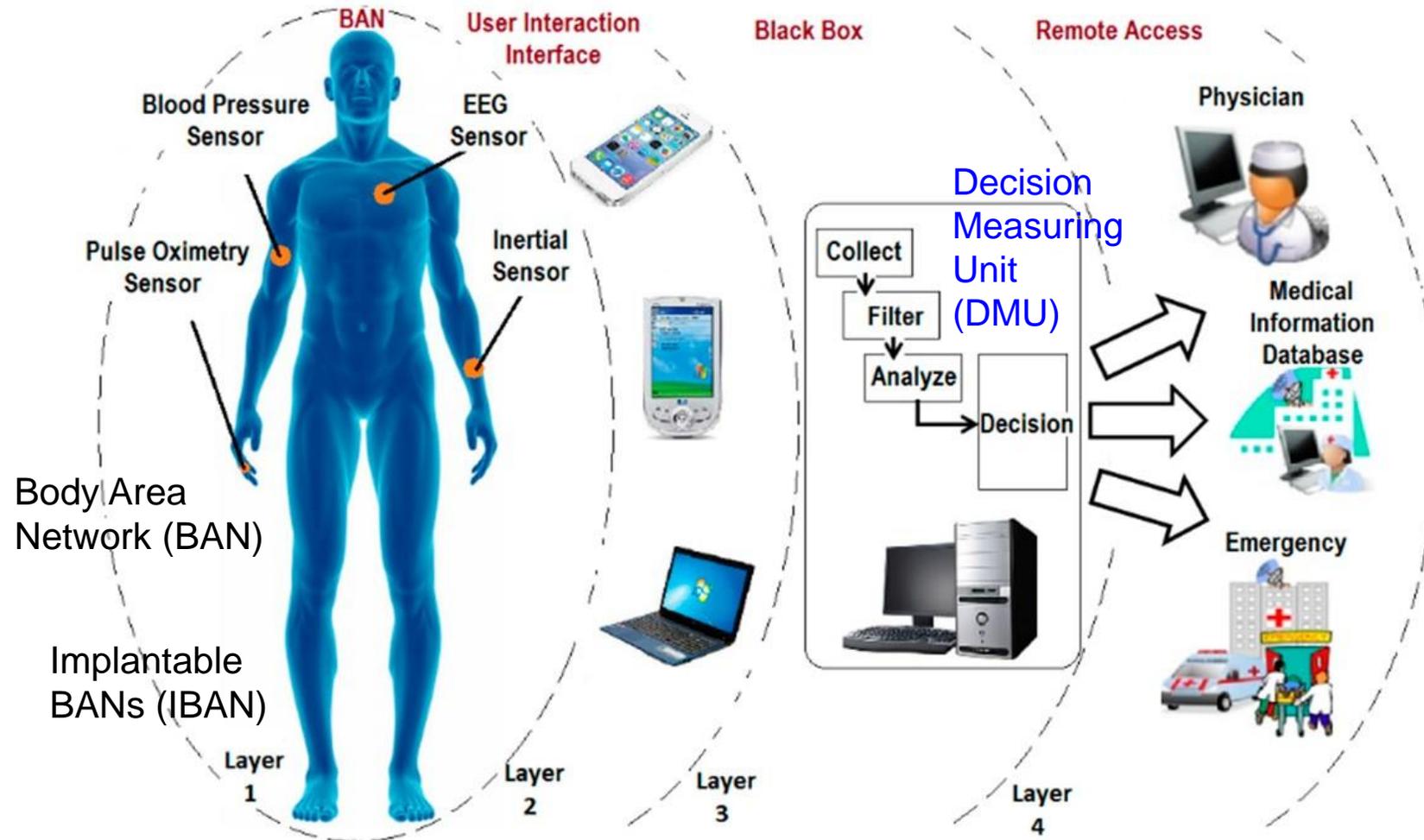
Internet of Medical Things (IoMT)

Internet of Health Things (IoHT)

Healthcare Cyber-Physical Systems (H-CPS)

Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", *IEEE Consumer Electronics Magazine (MCE)*, Volume 7, Issue 1, January 2018, pp. 18-28.

Smart Healthcare - 4-Layer Architecture



Healthcare Cyber-Physical Systems (H-CPS)

Source: M. Ghamari, B. Janko, R.S. Sherratt, W. Harwin, R. Piechockic, and C. Soltanpur, "A Survey on Wireless Body Area Networks for eHealthcare Systems in Residential Environments", *Sensors*, 2016. 16(6): p. 831.

Wearable Medical Devices (WMDs)



Fitness Trackers



Headband with Embedded Neurosensors

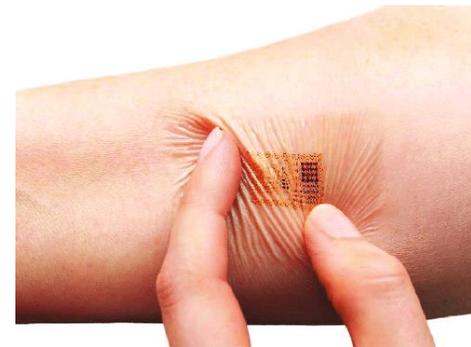


Source: <https://www.empatica.com/embrace2/>
Medical grade smart watch to detect seizure



Insulin Pump

Source: <https://www.webmd.com>

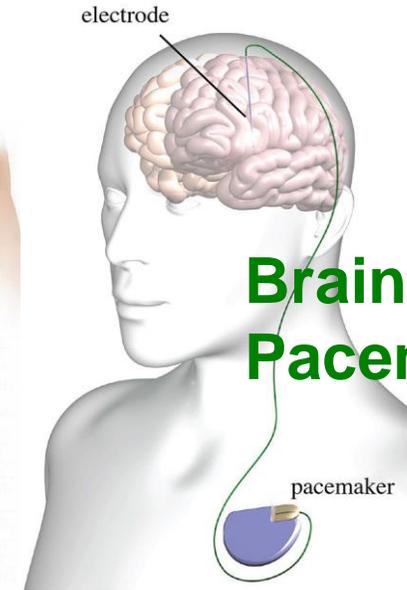
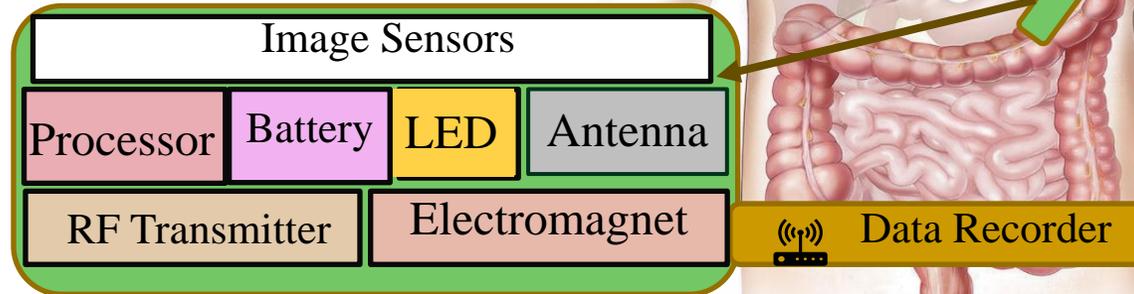
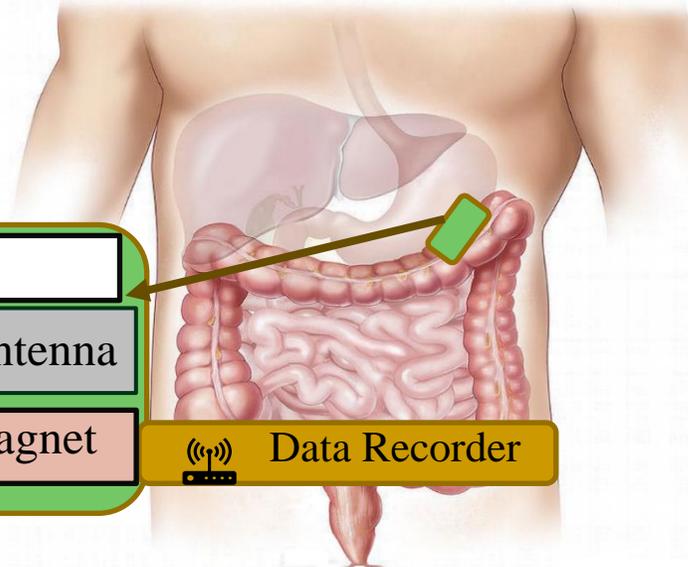


Embedded Skin Patches

Implantable Medical Devices (IMDs)



Pill Camera

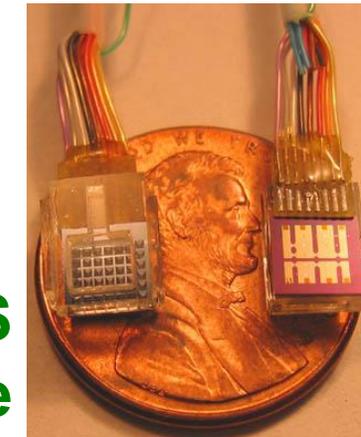


Brain Pacemaker

Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", IEEE Consumer Electronics Magazine (MCE), Volume 7, Issue 1, January 2018, pp. 18-28.

Collectively:
Implantable and Wearable
Medical Devices (IWMDs)

Implantable MEMS Device



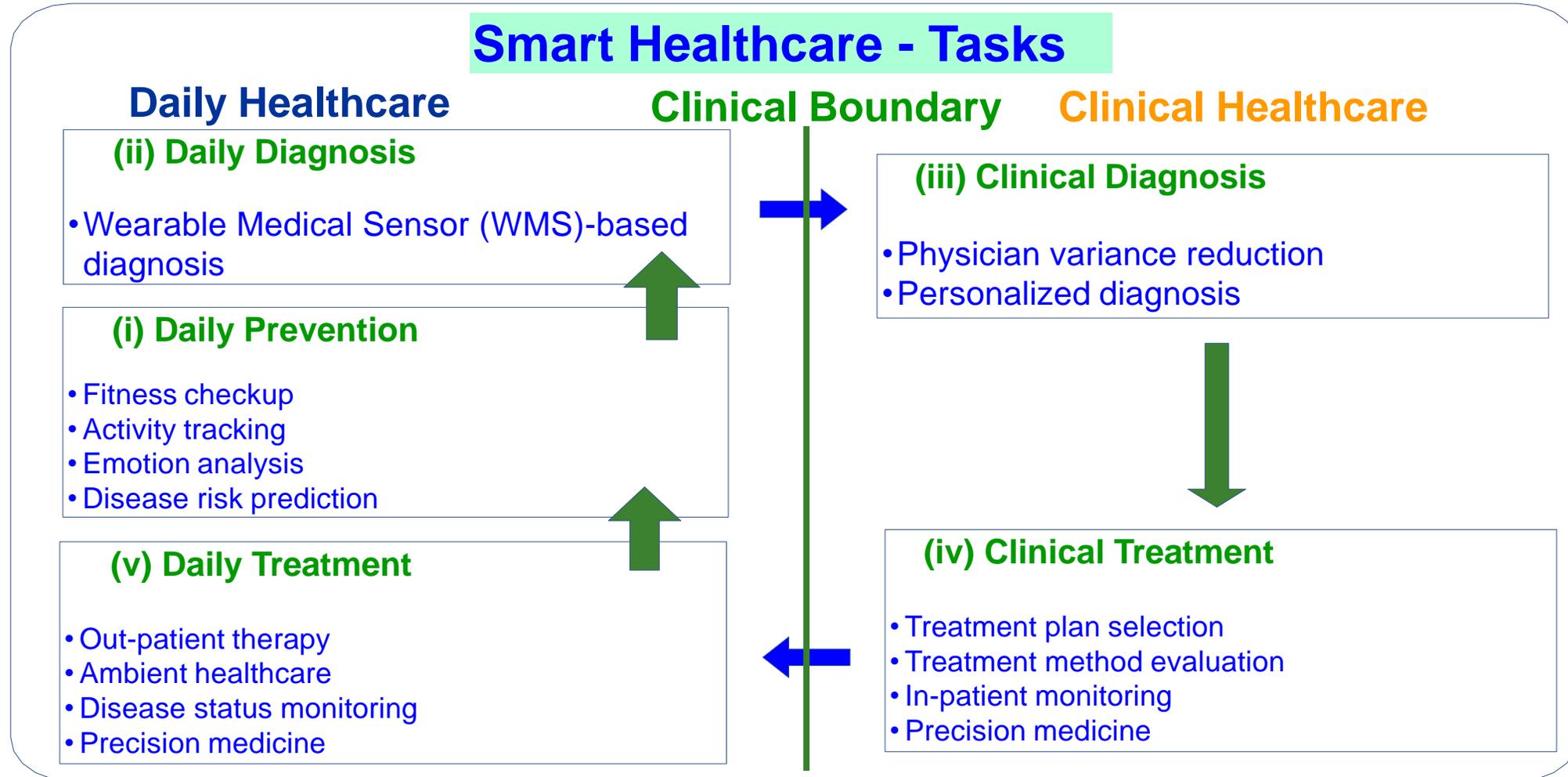
Source: <http://web.mit.edu/cprl/www/research.shtml>

Smart Healthcare – 7Ps



Source: H. Zhu, C. K. Wu, C. H. KOO, Y. T. Tsang, Y.Liu, H. R. Chi, and K. F. Tsang, "Smart Healthcare in the Era of Internet-of-Things", *IEEE Consumer Electronics Magazine*, vol. 8, no. 5, pp. 26-30, Sep 2019.

Smart Healthcare - Tasks



Source: Hongxu Yin, Ayten Ozge Akmandor, Arsalan Mosenia and Niraj K. Jha (2018), "Smart Healthcare", *Foundations and Trends® in Electronic Design Automation*: Vol. 12: No. 4, pp 401-466. <http://dx.doi.org/10.1561/10000000054>

IoMT Advantages & Limitations

Advantages

Patients/Users

- Real-time interventions in emergency
- Cost reduction
- Reduced morbidity and financial burden due to less follow up visits

Healthcare Service Providers

- Optimal utilization of resources
- Reduced response time in emergency

Manufacturers

- Standardization/compatibility and uniformity of data available
- Capability to sense and communicate health related information to remote location

Limitations

Technical Challenges

- ❖ Security of IoT data - hacking and unauthorized use of IoT
- ❖ Lack of standards and communication protocols
- ❖ Errors in patient data handling
- ❖ Data integration
- ❖ Need for medical expertise
- ❖ Managing device diversity and interoperability
- ❖ Scale, data volume and performance

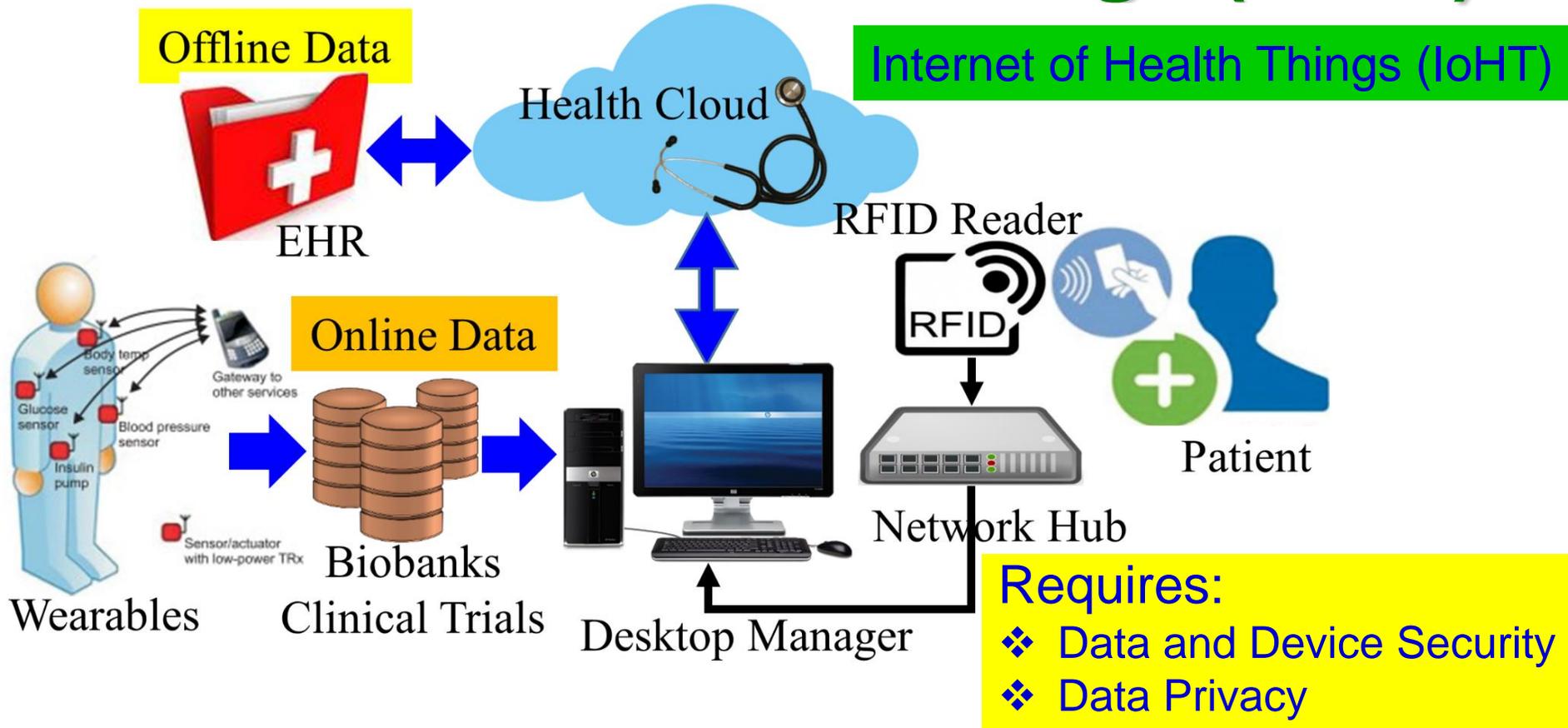
Market Challenges

- ❖ Physician compliance
- ❖ Data overload on healthcare facility
- ❖ Mobile hesitation
- ❖ Security policy compliance

Source: Y. Shelke and A. Sharma, "Internet of Medical Things", 2016, Aranca, <https://www.aranca.com/knowledge-library/special-reports/ip-research/the-internet-of-medical-things-iomt>, Last Visited 10/18/2017.

Smart Healthcare - Components

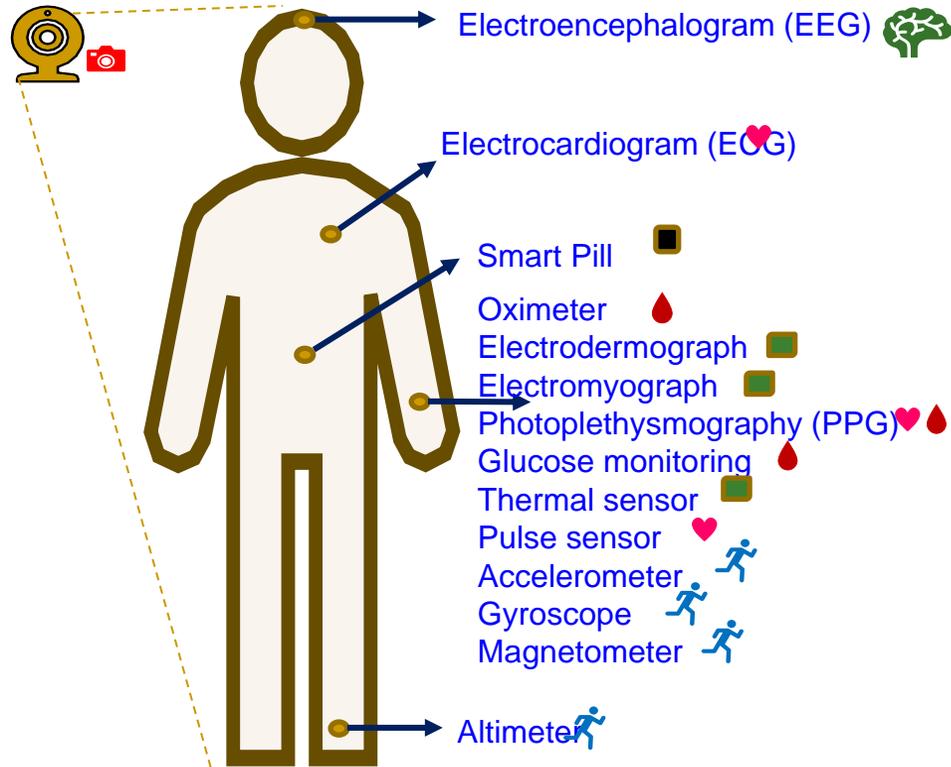
Internet of Medical Things (IoMT)



IoMT is a collection of medical sensors, devices, healthcare database, and applications that connected through Internet.

Source: <http://www.icemiller.com/ice-on-fire-insights/publications/the-internet-of-health-things-privacy-and-security/>
Source: <http://internetofthingsagenda.techtarget.com/definition/IoMT-Internet-of-Medical-Things>

Smart Healthcare Sensors



Types of Sensors	
	Brain related applications
	Imaging applications
	Heart related applications
	Skin related applications
	Blood related applications
	Ingestible sensors
	Motion Detection

Smart Healthcare Communication

Technology	Frequency Band	Data Rate	Range	Transmission Power
Bluetooth 4.0 (LE)	2.4 GHz	50–200 Kbps	30 m	~10 mW
Zigbee	868 MHz/ 915 MHz/ 2.4 GHz	20–250 Kbps	30 m	30 mW
ANT	2400-2485 MHz	1 Mbps	Up to 10 m	0.01–1 mW
IEEE 802.15.6	2,360-2,400/ 2,400-2,483.5 MHz UWB: 3–10 GHz HBC: 16/27 MHz	NB: 57.5–485.7 Kbps UWB: 0.5–10 Mbps	1.2 m	0.1 μ W
Medical Implant Communications Service (MICS)	402-405 MHz	Up to 500 Kbps	2 m	25 μ W

Source: V. Custodio, F.J. Herrera, G. López, and J. I. Moreno, “A Review on Architectures and Communications Technologies for Wearable Health-Monitoring Systems”, *Sensors*, 2012. 12(10): p. 13907-13946.

Electronics Health Record (EHR)

- Electronic Health Record (EHR) is the systematized collection of health information of individuals stored in a digital format.
- Created by various health providers such as hospitals and clinics.

The screenshot displays a medical software interface for 'Handy patients enterprise edition'. The patient information section shows David Anderson, 8 months and 10 days old, born on 5 January 2009. The 'Digestive' section includes fields for 'Digestive inspection' (Normal), 'Digestive auscultation' (Normal abdomen noises), and 'Digestive palpation' (Little pain on the right lower area). The interface also features a 'Meetings' table, a 'Diagnosis' section, and a 'Notes' section. The date is Thursday, 22 Jan 2009. The interface includes a 'Documents manager' and navigation buttons for 'Previous page' and 'Next page'.

Electronic Medical Record (EMR)

Smart Healthcare – AI/ML Framework

Smart Healthcare - System and Data Analytics : To Perform Tasks

Systems & Analytics

- Health cloud server
- Edge server
- Implantable Wearable Medical Devices (IWMDs)

Machine Learning Engine



Data

- Physiological data
- Environmental data
- Genetic data
- Historical records
- Demographics

Systems & Analytics

- Clinical Decision Support Systems (CDSSs)
- Electronic Health Records (EHRs)

Machine Learning Engine



Data

- Physician observations
- Laboratory test results
- Genetic data
- Historical records
- Demographics

Source: Hongxu Yin, Ayten Ozge Akmandor, Arsalan Mosenia and Niraj K. Jha (2018), "Smart Healthcare", *Foundations and Trends® in Electronic Design Automation*, Vol. 12: No. 4, pp 401-466. <http://dx.doi.org/10.1561/10000000054>

Brain Computer Interface (BCI)

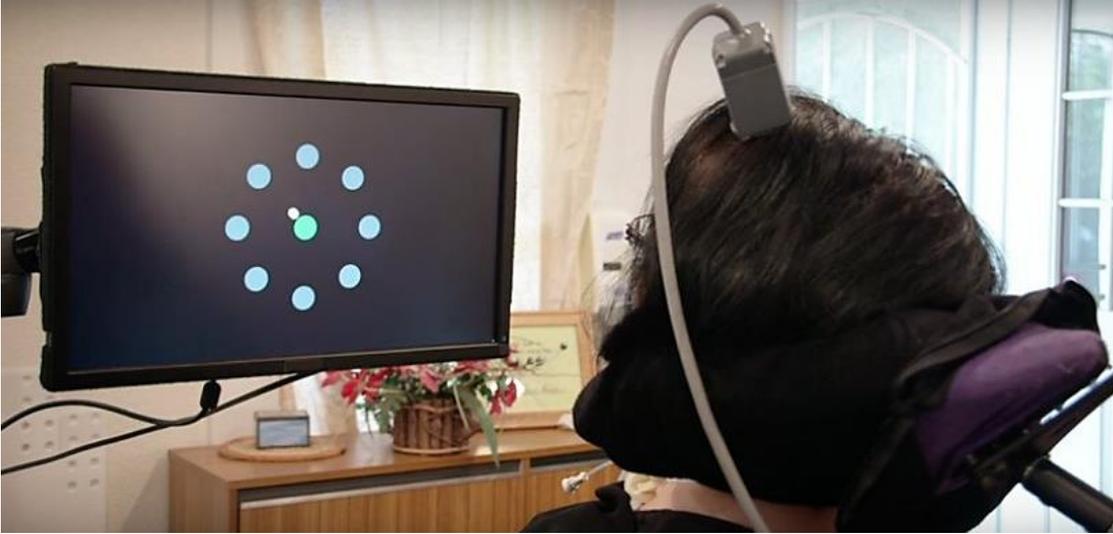
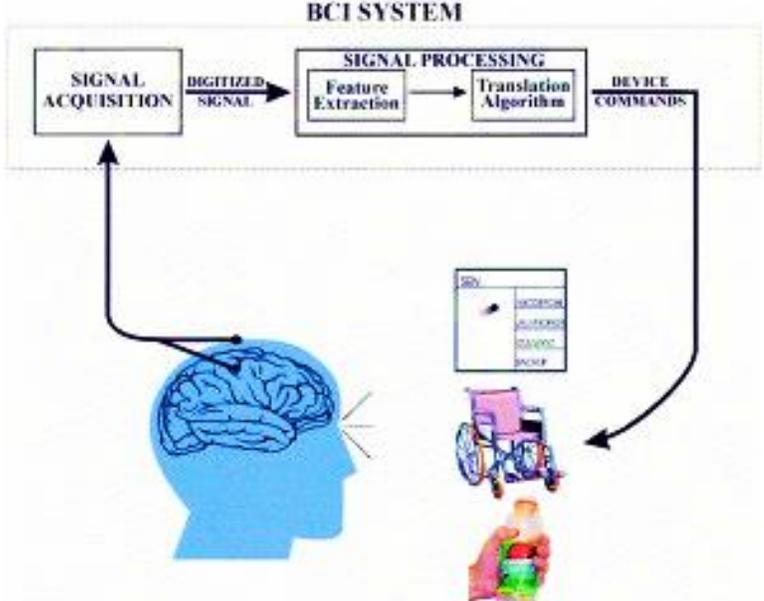


“Currently, people interact with their devices by thumb-typing on their phones. A high-bandwidth interface to the brain would help achieve a symbiosis between human and machine intelligence and could make humans more useful in an AI-driven world.”

-- Neuralink - neurotechnology company - Elon Musk.

Sources: <http://brainpedia.org/elon-musk-wants-merge-human-brain-ai-launches-neuralink/>

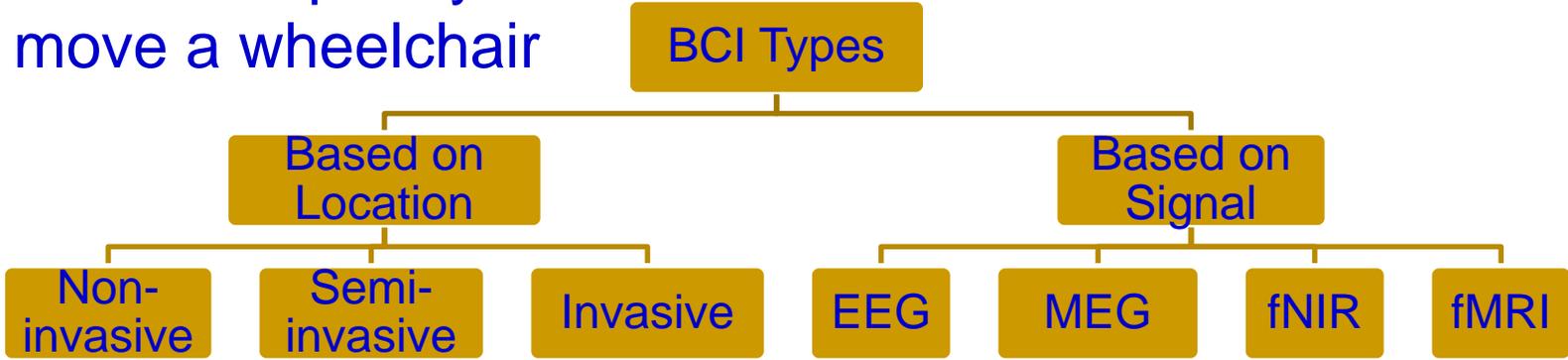
Brain Computer Interface (BCI)



Source: <http://brainpedia.org/brain-computer-interface-allows-paralysis-als-patients-type-much-faster/>

Source: <http://brainpedia.org/what-is-brain-computer-interface-bci/>
BCI Allows paralysis patients move a wheelchair

BCI Allows paralysis patients to Type



Virtual Reality in Healthcare



Source: <http://medicalfuturist.com/5-ways-medical-vr-is-changing-healthcare/>

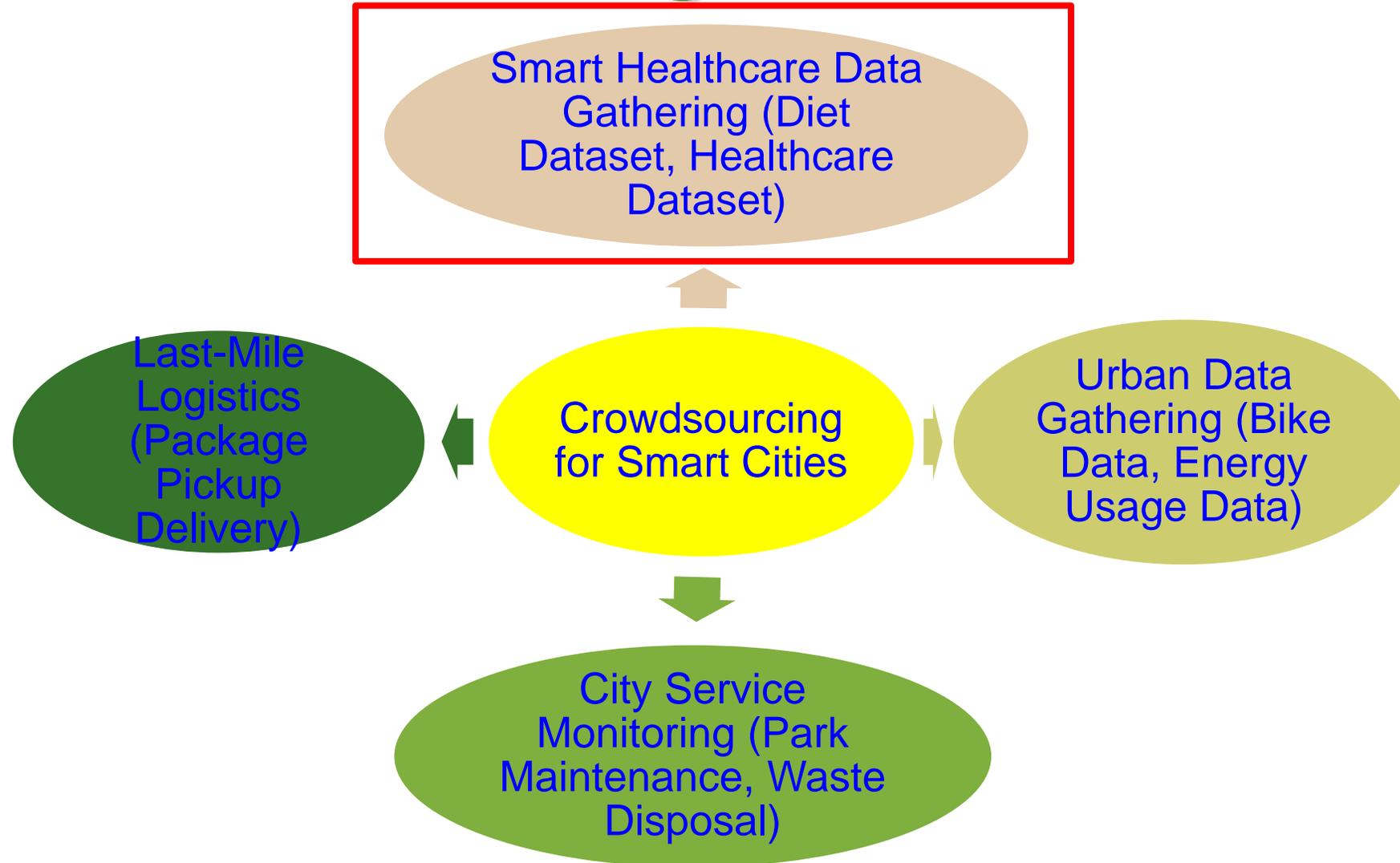
For Therapy



Source: <https://touchstoneresearch.com/tag/applied-vr/>

In Surgery

Crowdsourcing for Smart Cities



Smart Healthcare – Specific Examples

Stress Monitoring and Control is Needed

Stress is the **body's reaction** to any change that requires an adjustment or response.

Sudden encounter with **stress**

→ Brain floods **body** with chemicals and hormones
(**adrenaline and cortisol**)

- Lack of Energy
- Type 2 Diabetes
- Osteoporosis
- Mental cloudiness (brain fog) and memory problems
- A weakened immune system, leading to more vulnerable to infections



Distress



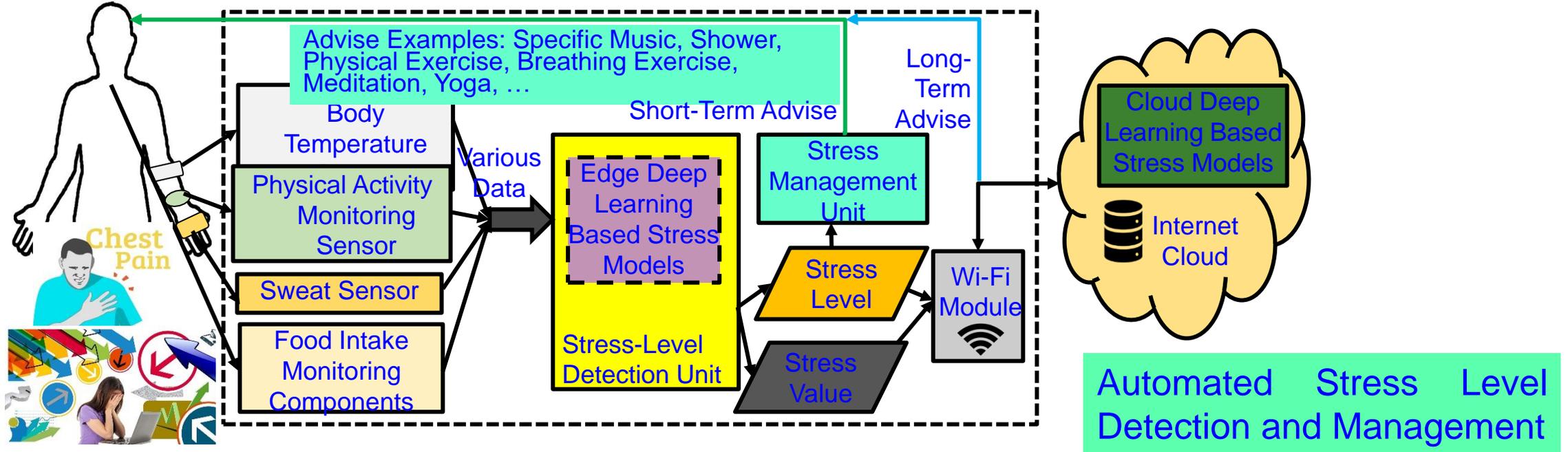
Eustress

Stress is a Global Issue

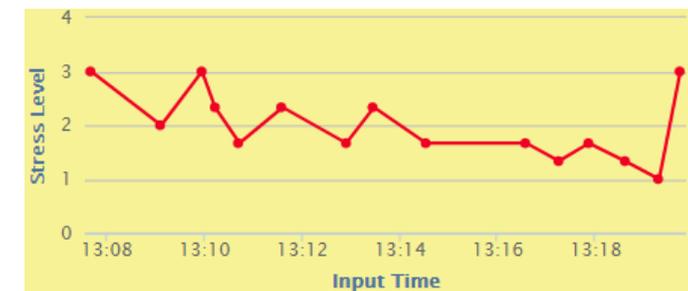
- In major global economies - 6 in 10 workers experiencing increased workplace stress.
- In USA: 75% of adults reported experiencing moderate to high levels of stress. 1 out of 75 people may experience panic disorder.
- In Australia: 91% of adults feel stress in at least one important area of their lives.
- In UK: An estimated 442,000 individuals, who worked in 2007/08 believed that they were experiencing work-related stress
- Depression is among the leading causes of disability worldwide. 25% of those with depression world-wide have access to effective treatments → 75% don't have.

Source: <http://www.gostress.com/stress-facts/>

Stress Monitoring & Control – Our Vision



Sensor	Low Stress	Normal Stress	High Stress
Accelerometer (steps/min)	0-75	75-100	101-200
Humidity (RH%)	27-65	66-91	91-120
Temperature °F	98-100	90-97	80-90



Source: L. Rachakonda, S. P. Mohanty, E. Kougianos, and P. Sundaravadivel, "Stress-Lysis: A DNN-Integrated Edge Device for Stress Level Detection in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 65, No 4, Nov 2019, pp. 474--483.

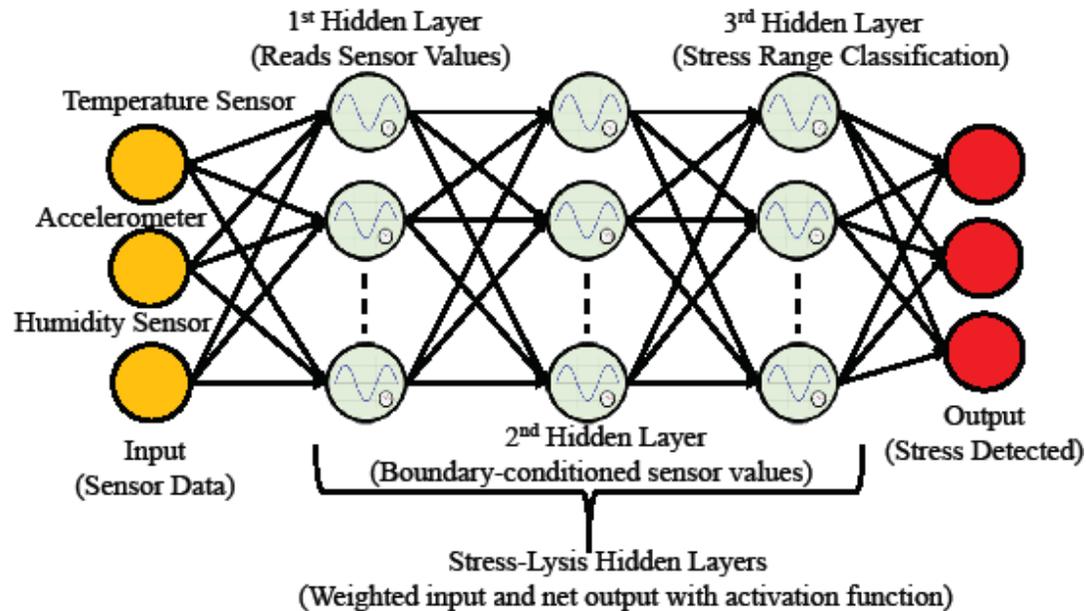
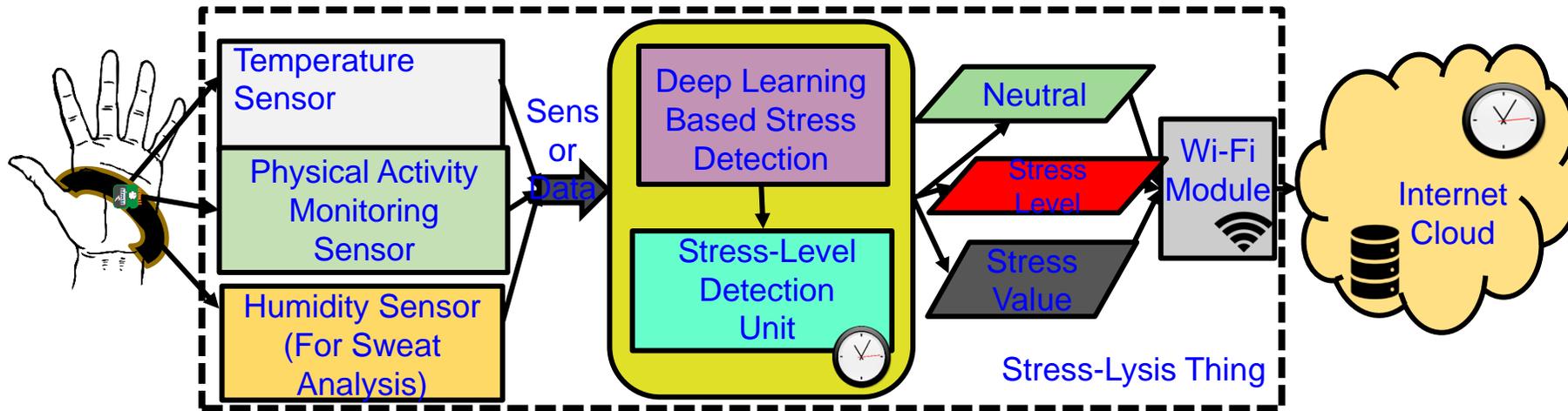
Consumer Electronics Devices – Can Provide Data for Stress Detection

Brand	Device	Signals	RTI	Ambulant
Empatica	E4 wristband	PPG, GSR, HR, ACC, ST	Yes	Yes
Garmin	Vivosmart	HR, HRV, ACC	Yes	Yes
Zephyr	BioHarness 3.0	HR, HRV, GSR, ACC, ST	Yes	Yes
iMotions	Shimmer 3+ GSR	GSR, PPG	Yes	No
BIOPAC	Mobita Wearable	ECG, EEG, EGG, EMG, and EOG	Yes	No

GSR = Galvanic Skin Response, HR = Heart Rate, ACC = Acceleration, ST = Skin Temperature, HRV = Heart Rate Variability, PPG = Photoplethysmograph, RTI = Real Time Implementation

Source: R. K. Nath, H. Thapliyal, A. Caban-Holt, and S. P. Mohanty, "Machine Learning Based Solutions for Real-Time Stress Monitoring", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 9, No. 5, September 2020, pp. 34--41.

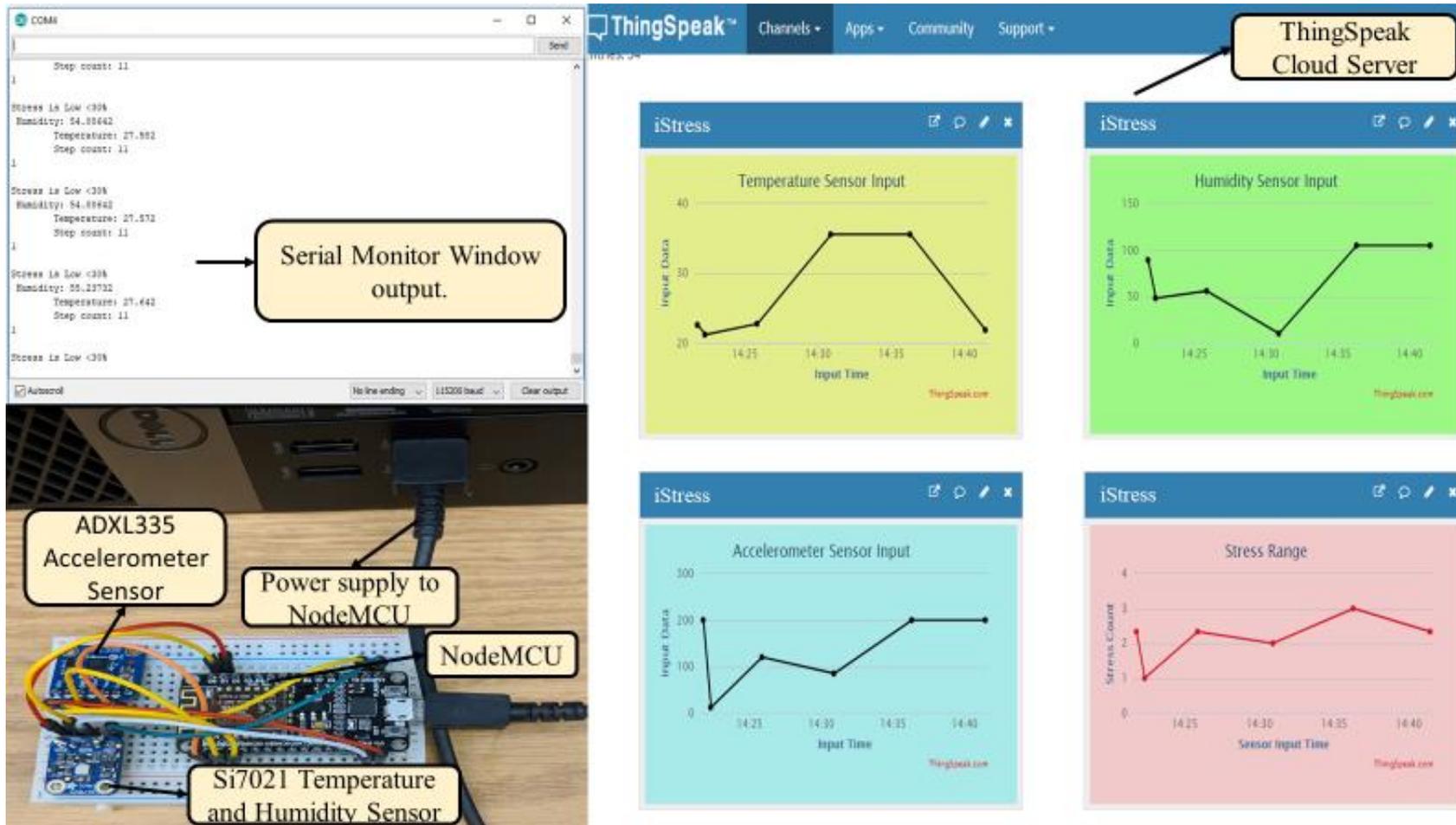
Stress-Lysis: From Physiological Signals



Stress-Lysis - DNN has been trained with a total of 26,000 samples per dataset and has accuracy upto 99.7%.

Source: L. Rachakonda, S. P. Mohanty, E. Kougianos, and P. Sundaravadivel, "Stress-Lysis: A DNN-Integrated Edge Device for Stress Level Detection in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 65, No 4, Nov 2019, pp. 474--483.

Stress-Lysis: Experiments



Stress-Lysis - DNN has been trained with a total of 26,000 samples per dataset and has accuracy upto 99.7%.

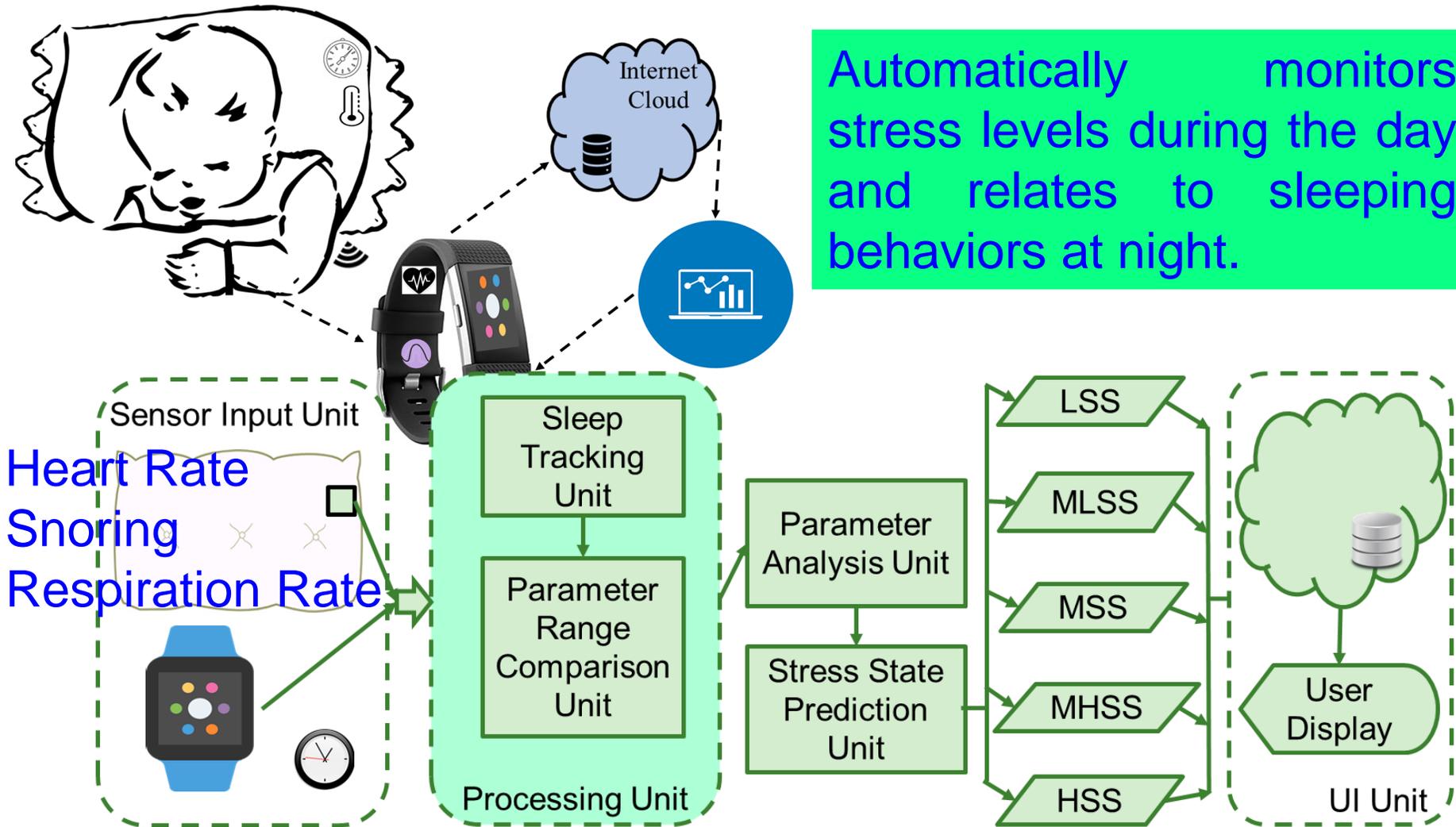
Source: L. Rachakonda, S. P. Mohanty, E. Kougianos, and P. Sundaravadivel, "Stress-Lysis: A DNN-Integrated Edge Device for Stress Level Detection in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 65, No 4, Nov 2019, pp. 474--483.

Consumer Electronics Sleep Trackers

Consumer Products	Approach	Features	Drawbacks
Fitbit [34]	Wearable	Heart rate monitor, sleep stages monitor. Has techniques to improve the sleep score.	Relationship between stress and sleep is not discussed.
SleepScore Max [36]	Non-wearable	Invisible radio wave sleep tracking	Does not manage stress with sleep.
Nokia Sleep [38]	Non-wearable	Uses Ballistocardiography sensor	Does not explain the relationship with stress with sleep.
Xiaomi Mi Band 3 [31]	Wearable	Pulse Monitor	No information on importance of quality sleep.
Eversleep [32]	wearable	Snoring and breathing interruptions	No explanation on the relationship between stress and sleep.
Beddit [35]	Non-wearable	Monitors snoring	Doesn't consider other possible features.
Eight [37]	Non-Wearable	Humidity, temperature, heartbeat, breathing rate	No data on how it is important to have a good sleep.
Dreem [33]	Wearable	Simulates slow brain waves	It doesn't consider other features; Does not manage stress with sleep.
Muse [26]	Wearable	Simulates brain waves	No understanding of the importance of quality sleep.

Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: A Blockchain-Enabled, Privacy-Assured Framework for Stress Detection, Prediction and Control Considering Sleeping Habits in the IoMT", *arXiv Computer Science*, arXiv:2007.07377, July 2020, 38-pages.

Smart Healthcare – Smart-Pillow



Automatically monitors stress levels during the day and relates to sleeping behaviors at night.

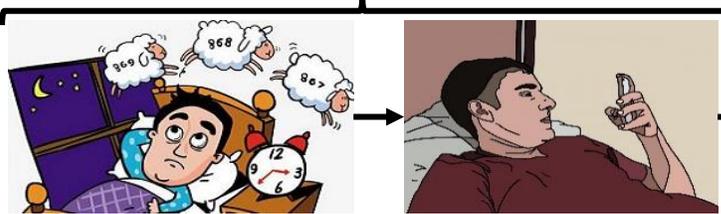
Source: L. Rachakonda, S. P. Mohanty, E. Kougianos, K. Karunakaran, and M. Ganapathiraju, "Smart-Pillow: An IoT based Device for Stress Detection Considering Sleeping Habits", in *Proceedings of the 4th IEEE International Symposium on Smart Electronic Systems (iSES)*, 2018, pp. 161--166.

Smart-Yoga Pillow (SaYoPillow) - Sleeping Pattern

Person On Pillow:
Physiological Sensor Data Monitoring Starts



Period 1. Lying on bed but not Sleeping



Person Off Pillow:
Physiological Sensor Data Monitoring Ends



Period 5: Awake Person



Period 3: Drift from Wakefulness to Sleep



Period 2: Trying to Sleep



Period 4: Deep Sleep

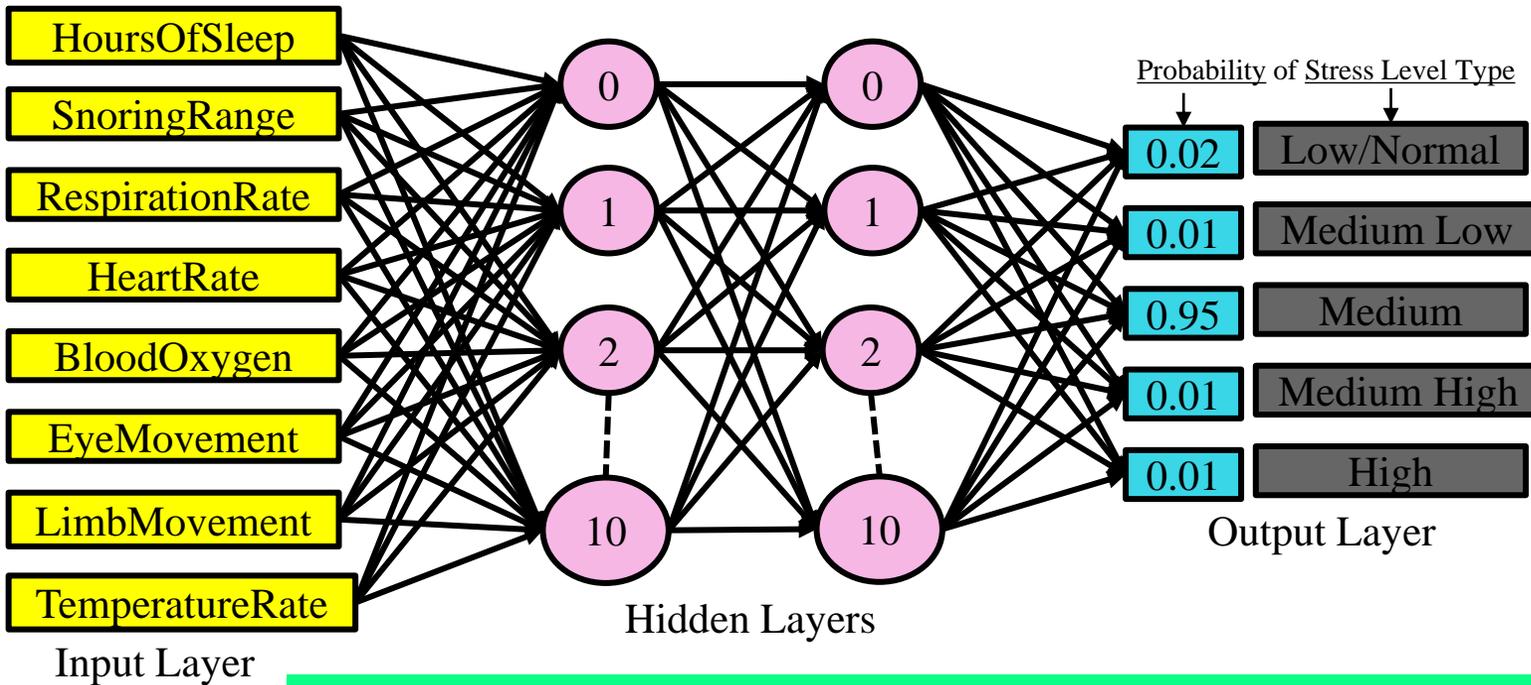


Transitions of a person drifting into non-rapid eye movement (NREM) followed by rapid eye movement (REM) to Awake State.

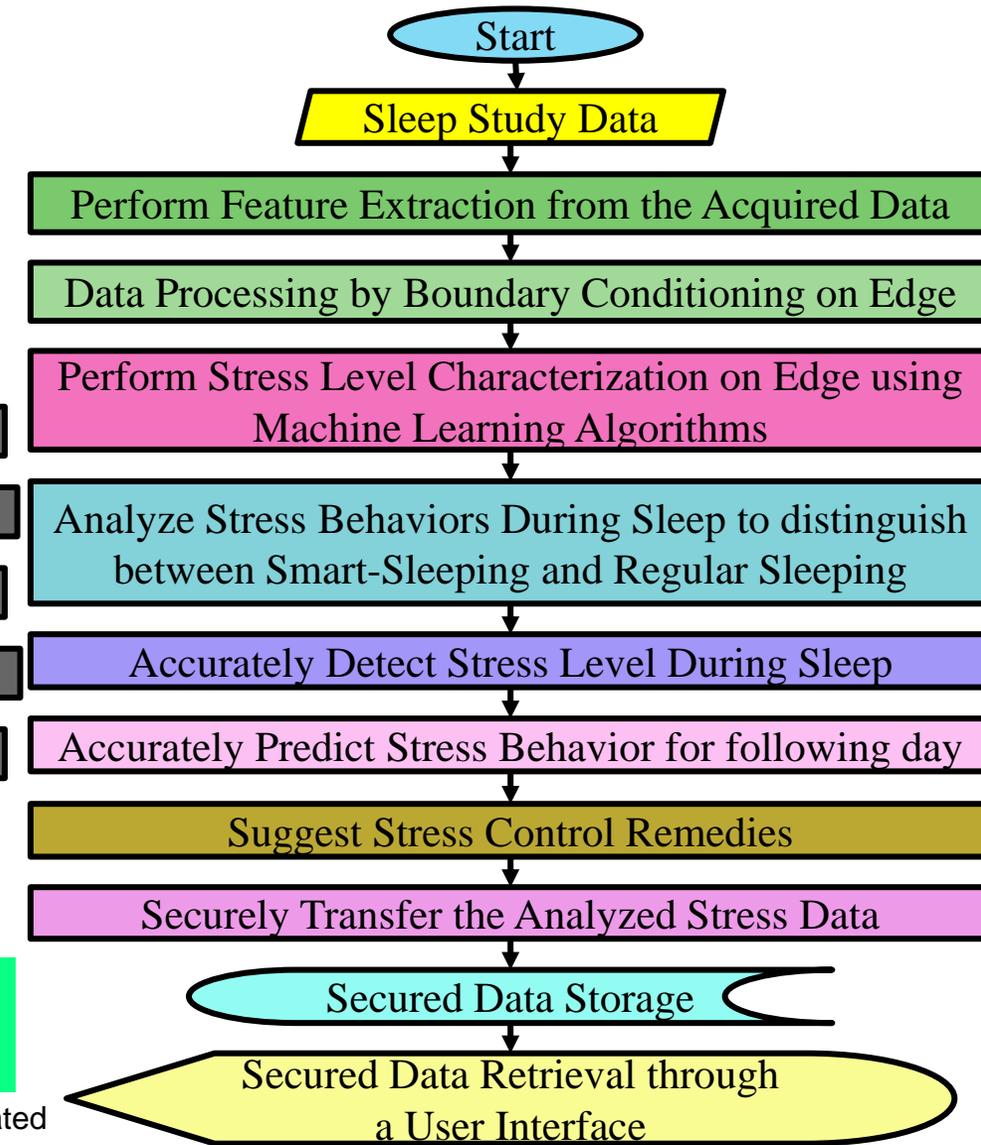


Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

SaYoPillow – Stress Analysis Approach

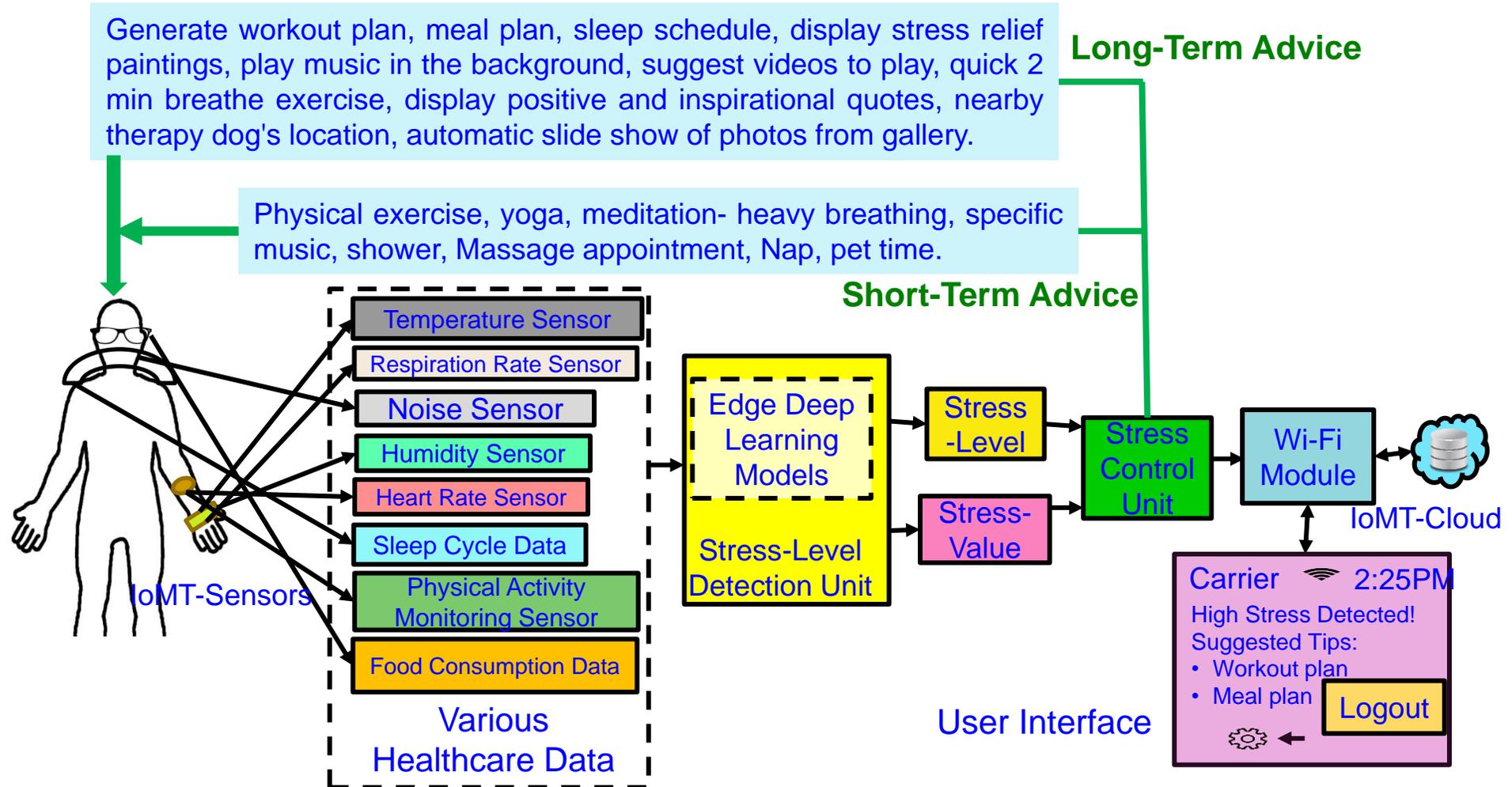


SaYoPillow – Uses deep learning for 96% accuracy with blockchain based security features



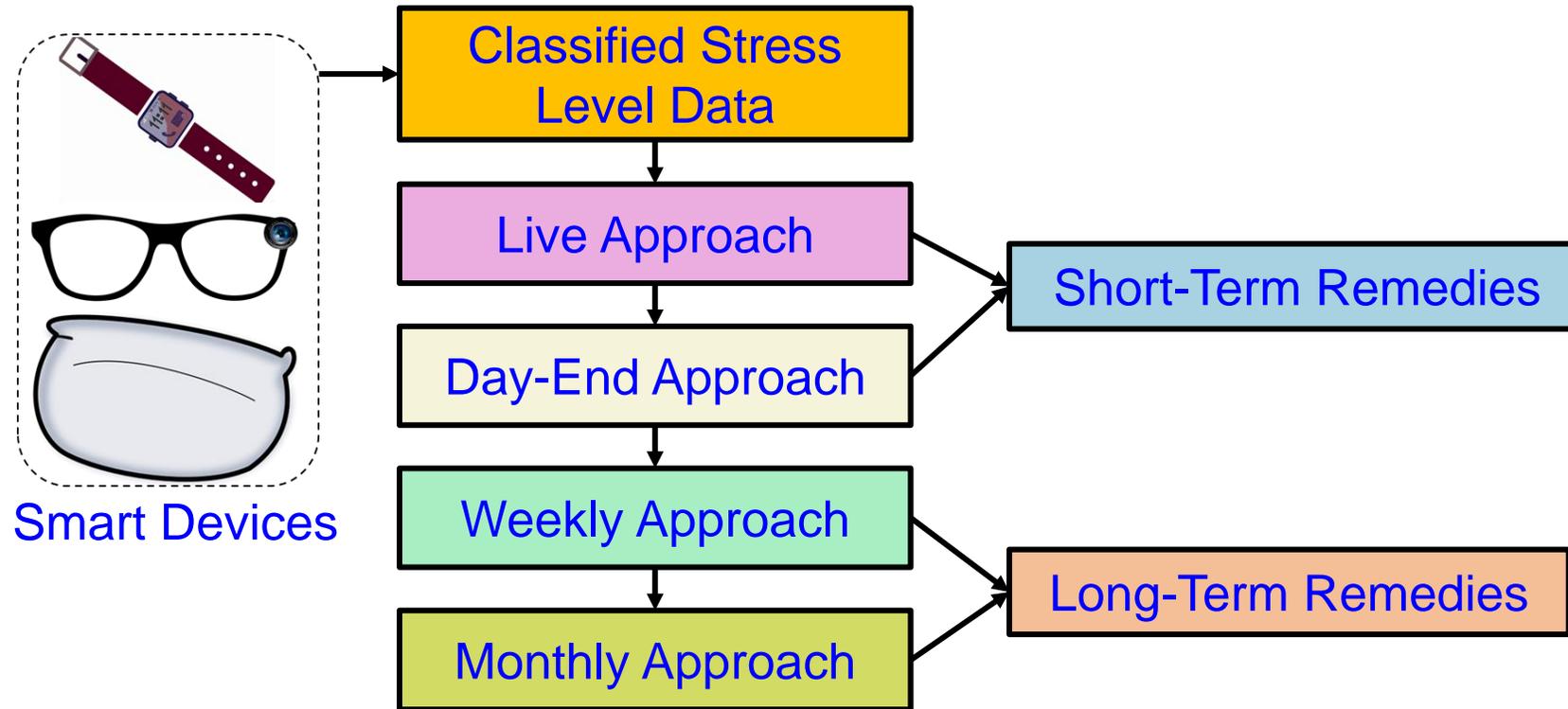
Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

Stress Control by iFeliz: Our Proposed System



Source: L. Rachakonda, S. P. Mohanty, and E. Kougianos, "iFeliz: An Approach to Control Stress in the Midst of the Global Pandemic and Beyond for Smart Cities using the IoMT", in *Proc. of IEEE Smart Cities Conference (ISC2)*, 2020.

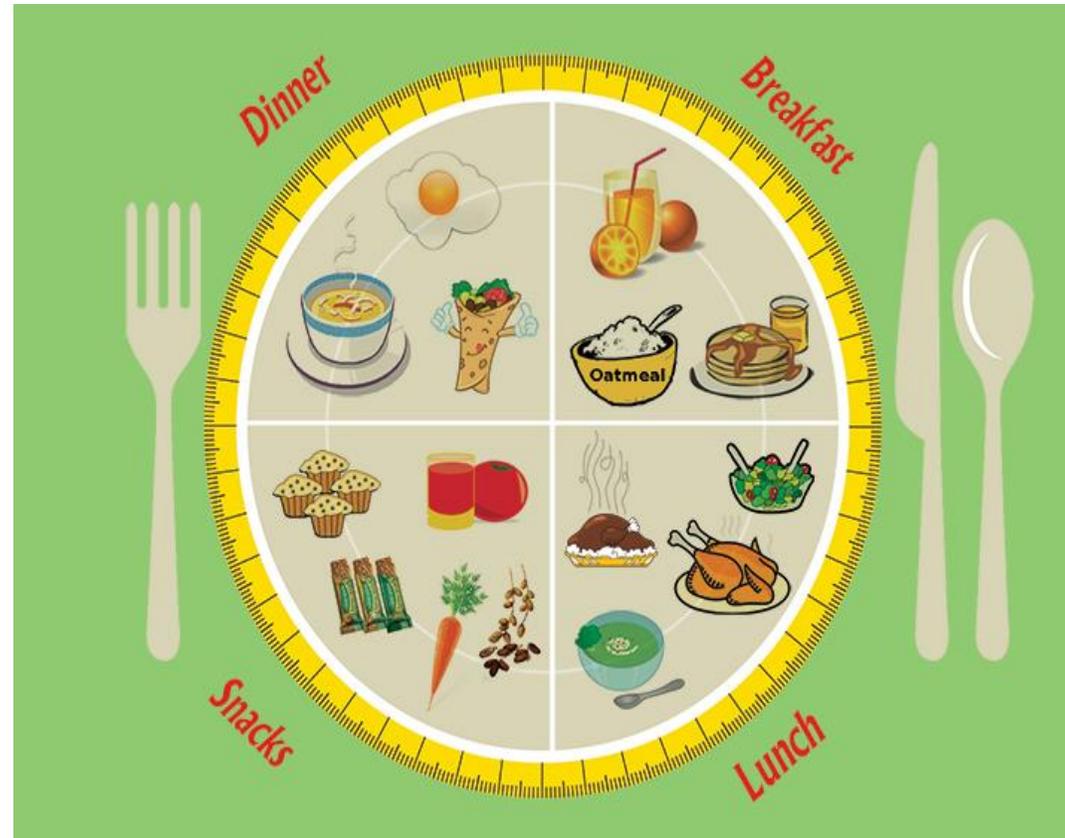
iFeliz: Stress Control Approaches



iFeliz - 15 Features, Stress Detection, Stress Control, Accuracy - 97%.

Source: L. Rachakonda, S. P. Mohanty, and E. Kougianos, "iFeliz: An Approach to Control Stress in the Midst of the Global Pandemic and Beyond for Smart Cities using the IoMT", in *Proc. of IEEE Smart Cities Conference (ISC2)*, 2020.

Automatic Food Intake Monitoring and Diet Management is Important



Imbalance Diet is a Global Issue

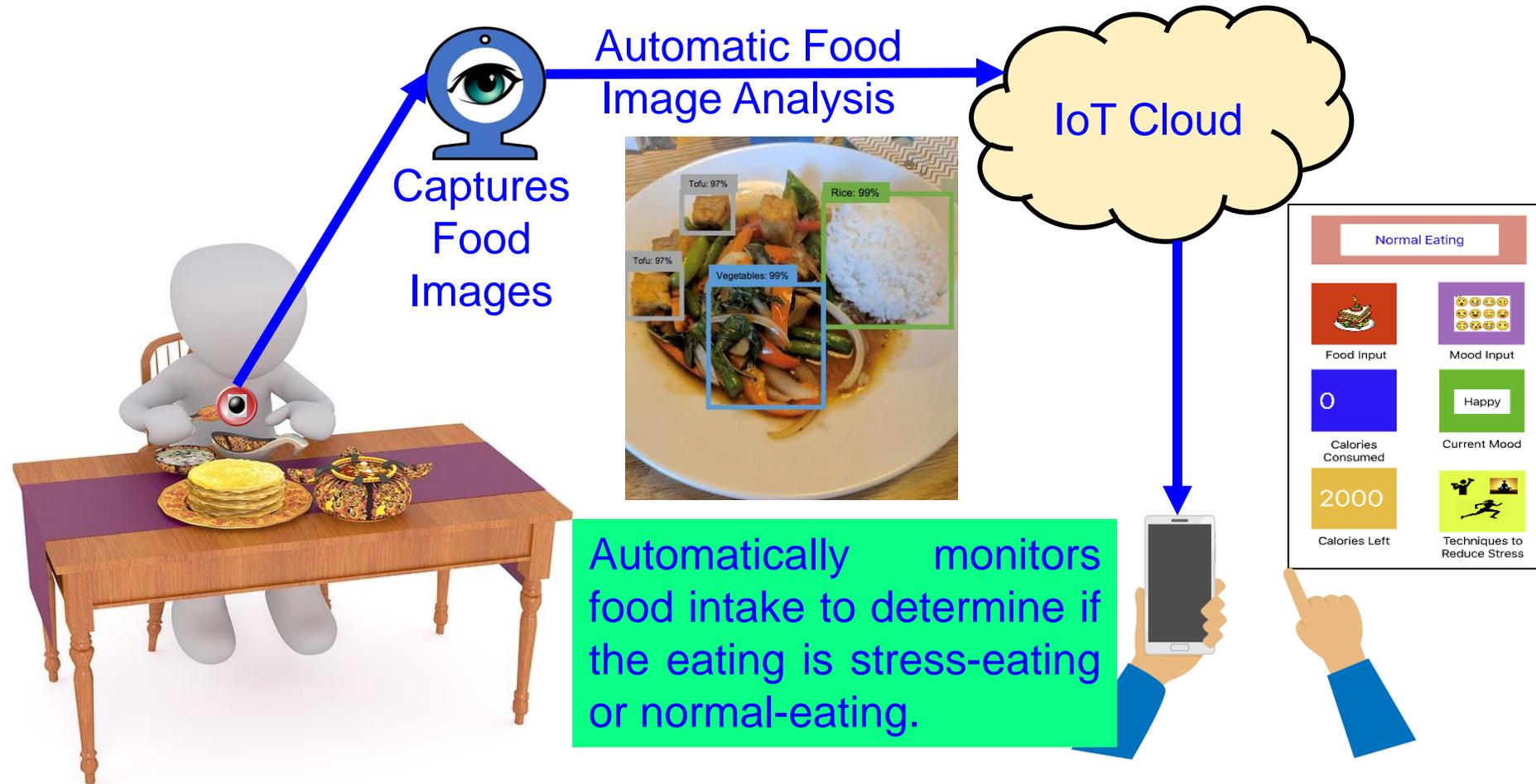
- Imbalanced diet can be either more or fewer of certain nutrients than the body needs.
- In 2017, 11 million deaths and 255 million disability-adjusted life-years (DALYs) were attributable to dietary risk factors.
- Eating wrong type of food is potential cause of a dietary imbalance:

- Psychiatric disorders
- Coronary heart disease
- High blood pressure

- Obesity
- Tooth decay
- Diabetes

Source: <https://obesity-diet.nutritionalconference.com/events-list/imbalanced-diet-effects-and-causes>
[https://www.thelancet.com/article/S0140-6736\(19\)30041-8/fulltext](https://www.thelancet.com/article/S0140-6736(19)30041-8/fulltext)

Automatic Diet Monitoring & Control - Our Vision



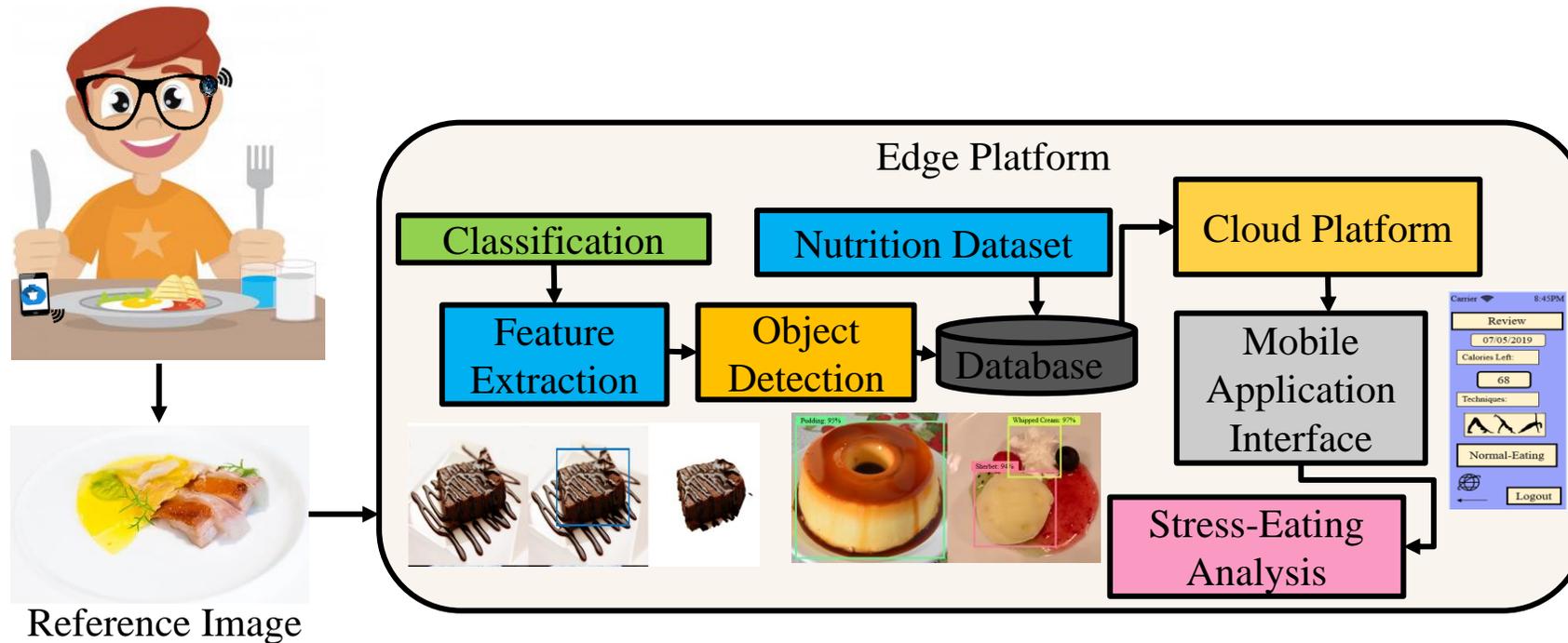
Source: L. Rachakonda, S. P. Mohanty, and E. Kougianos, "iLog: An Intelligent Device for Automatic Food Intake Monitoring and Stress Detection in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 66, No. 2, May 2020, pp. 115--124.

Food Tracking Apps

Table 1. Overview of popular food tracking approaches and their capabilities.

App Name	Downloa ds	Reviews	Rating	Imag e	Input Method			Manu al	Scan ning	Spee ch	Datab ase searc h	Calori es	Nutriti on
					Food-Label in Image								
					Auto	Man ual	Crow d Sour ced						
MyFitnessPal	50 M	2 M	4.6					X	X			X	
FatSecret	10 M	268 k	4.5					X	X			X	X
My Diet Coach	10 M	144 k	4.4					X				X	
Lose it	10 M	77 k	4.4	X				X	X			X	
MyPlate	1 M	31 k	4.6					X	X			X	X
mynetdiary	1 M	31 k	4.5					X				X	X
Macros	500 k	3 k	4.5					X	X			X	
Cron-o-meter	100 k	1 k	4.2					X					
Eating Habit	100 k	549	4	X			X					X	
21 day Fix	100 k	470	3.7					X				X	
Bite Snap	50 k	2k	4.7	X								X	X
MealLogger	50 k	225	3.5	X				X				X	X
EatRight	10 k	220	4.5					X				X	
Keto Meal Plan	10 k	19	2.6								X		
YouAte	10 k			X									
KudoLife	1 k	11	3.4								X	X	X
Calorific	19		3.2								X		
Ate				X				?				?	?
Foodlog				X	X			X				X	

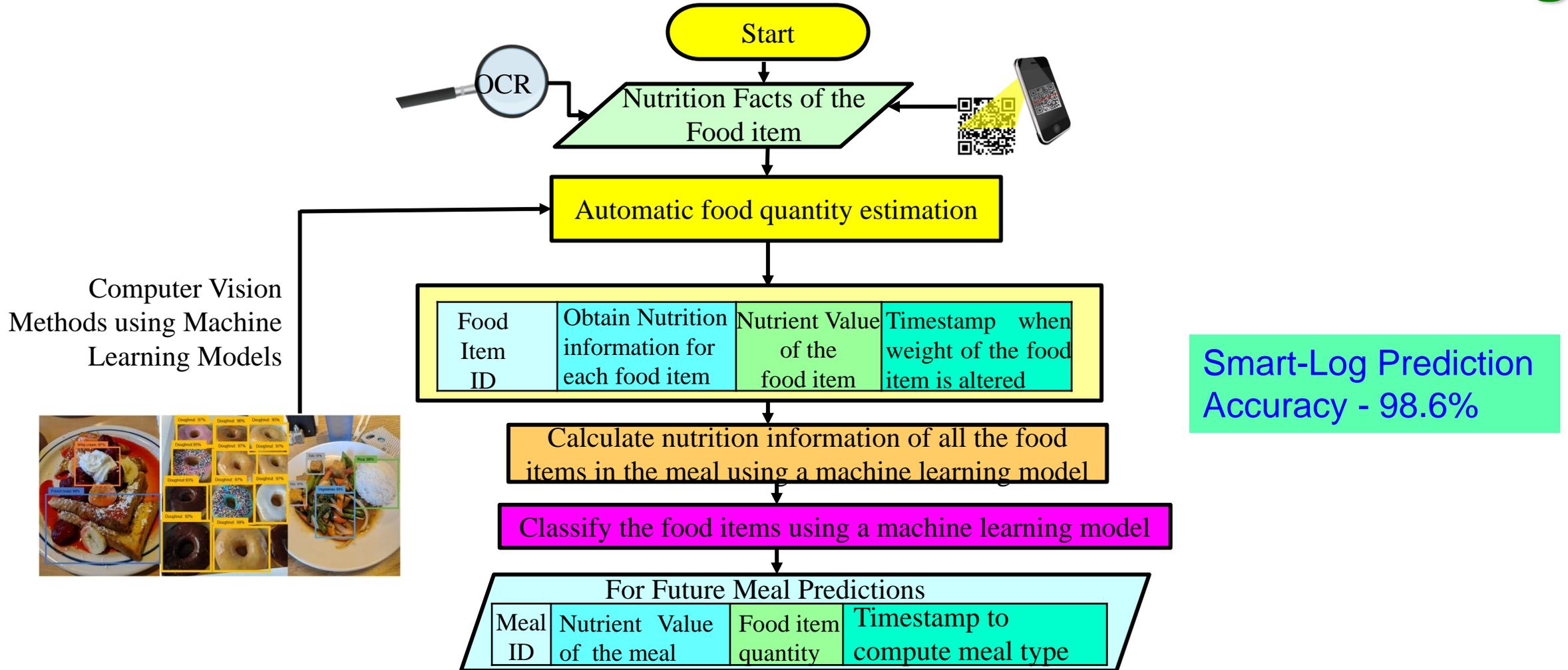
Smart Healthcare – Diet Monitoring - iLog



iLog- Fully Automated Detection System with 98% accuracy.

Source: L. Rachakonda, S. P. Mohanty, and E. Kougianos, "iLog: An Intelligent Device for Automatic Food Intake Monitoring and Stress Detection in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 66, No. 2, May 2020, pp. 115--124.

Smart Healthcare – Diet Prediction – Smart-Log



Source: P. Sundaravadivel, K. Kesavan, L. Kesavan, **S. P. Mohanty**, and E. Kougianos, "Smart-Log: A Deep-Learning based Automated Nutrition Monitoring System in the IoT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 64, Issue 3, Aug 2018, pp. 390-398.

Elderly Fall Automatic Detection is Needed to Improve Quality of Life

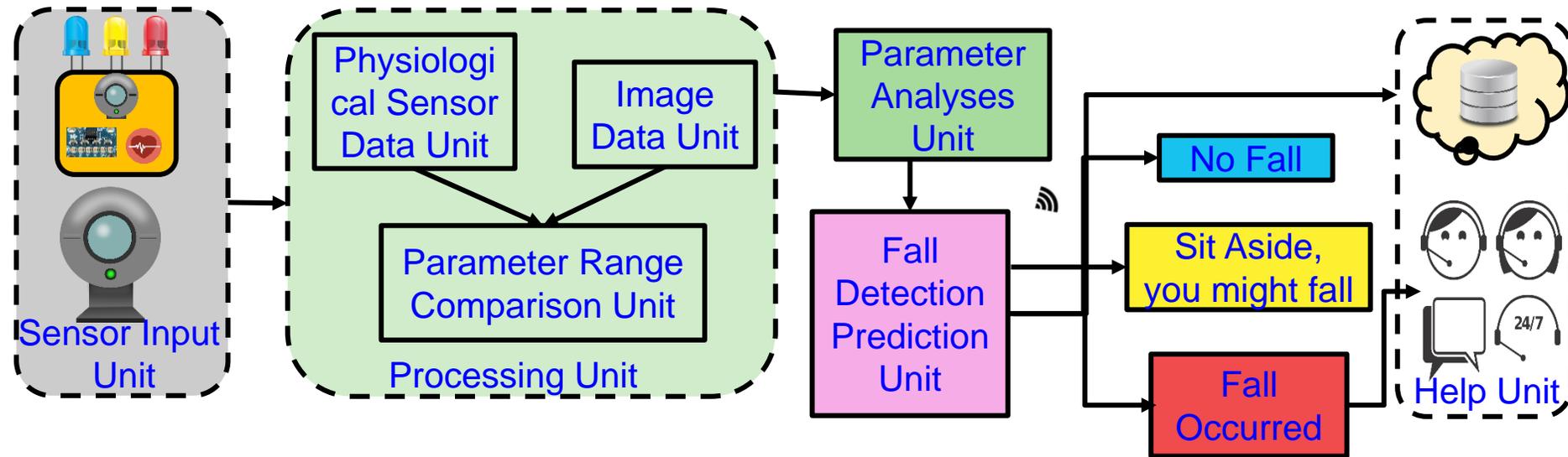
- Elderly Fall: Approximately a third of elderly people 65 years or older fall each year.
- Fall Caused → Over 800,000 hospital admissions, 2.8 million injuries and 27,000 deaths have occurred in the last few years.

Source: L. Rachakonda, A. Sharma, S. P. Mohanty, and E. Kougianos, "Good-Eye: A Combined Computer-Vision and Physiological-Sensor based Device for Full-Proof Prediction and Detection of Fall of Adults", in *Proceedings of the 2nd IFIP International Internet of Things (IoT) Conference (IFIP-IoT)*, 2019, pp. 273--288.

Consumer Electronics for Fall Detection

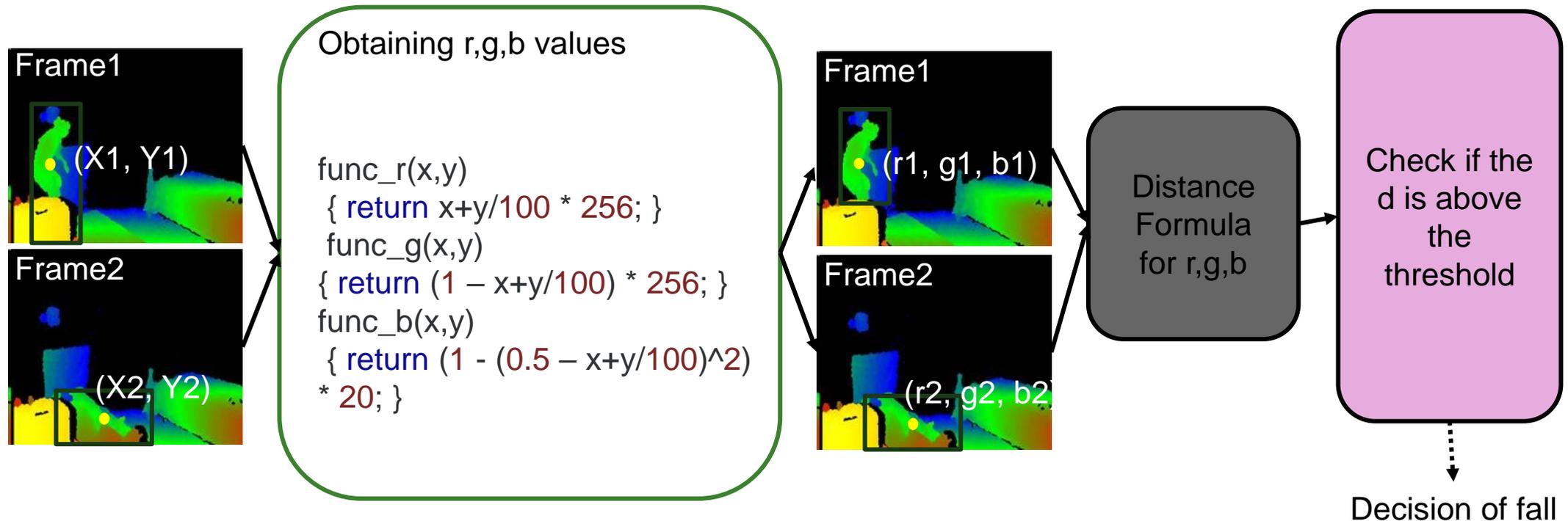
Wearables	Drawbacks
	Apple watch: uses only accelerometers, doesn't work on low thresholds like double carpet, bathroom, hardwood floors. The user must manually select the option SOS and as a reason it fails if the person is unconscious. Users may remain on the floor with no help for large hours.
	Philips Lifeline: Uses only accelerometers and barometric sensors for pressure changes. After the fall, the system waits for 30 sec and directly connects to help.
	Lively Mobile by greatcall and Sense4Care Angel4: Monitors fluctuations using only accelerometers.
	Bay Alarm Medical and Medical Guardian: Use only accelerometers. Have huge base stations limiting the usage and location access.

Good-Eye: Our Multimodal Sensor System for Elderly Fall Prediction and Detection



Source: L. Rachakonda, A. Sharma, S. P. Mohanty, and E. Kougianos, "Good-Eye: A Combined Computer-Vision and Physiological-Sensor based Device for Full-Proof Prediction and Detection of Fall of Adults", in *Proceedings of the 2nd IFIP International Internet of Things (IoT) Conference (IFIP-IoT)*, 2019, pp. 273--288.

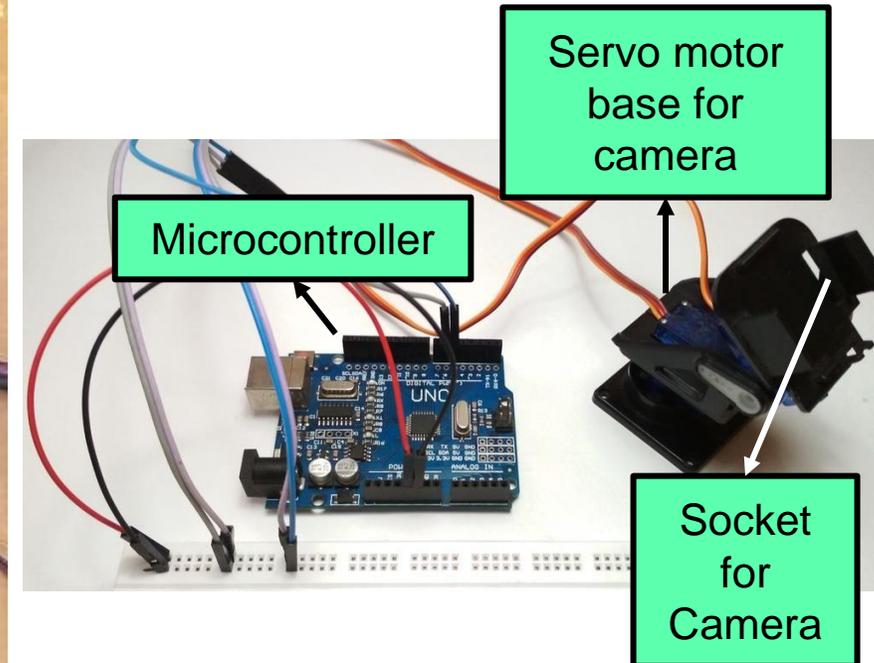
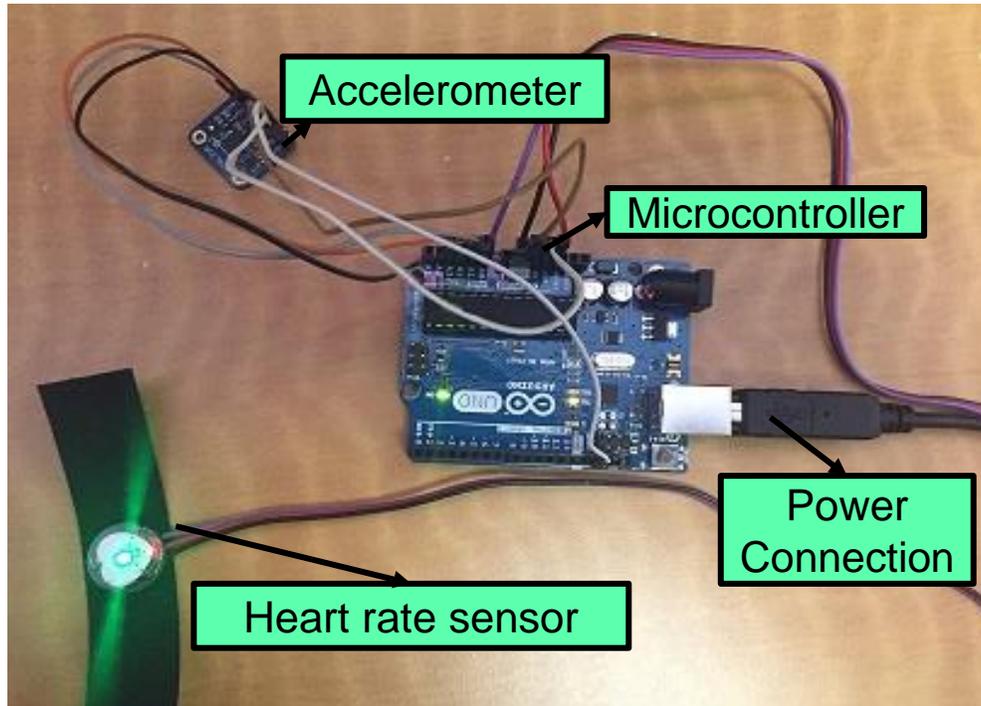
Good-Eye: Elderly Fall Detection



Good-Eye: Fall detection and prediction Accuracy - 95%.

Source: L. Rachakonda, A. Sharma, S. P. Mohanty, and E. Kougianos, "Good-Eye: A Combined Computer-Vision and Physiological-Sensor based Device for Full-Proof Prediction and Detection of Fall of Adults", in *Proceedings of the 2nd IFIP International Internet of Things (IoT) Conference (IFIP-IoT)*, 2019, pp. 273--288.

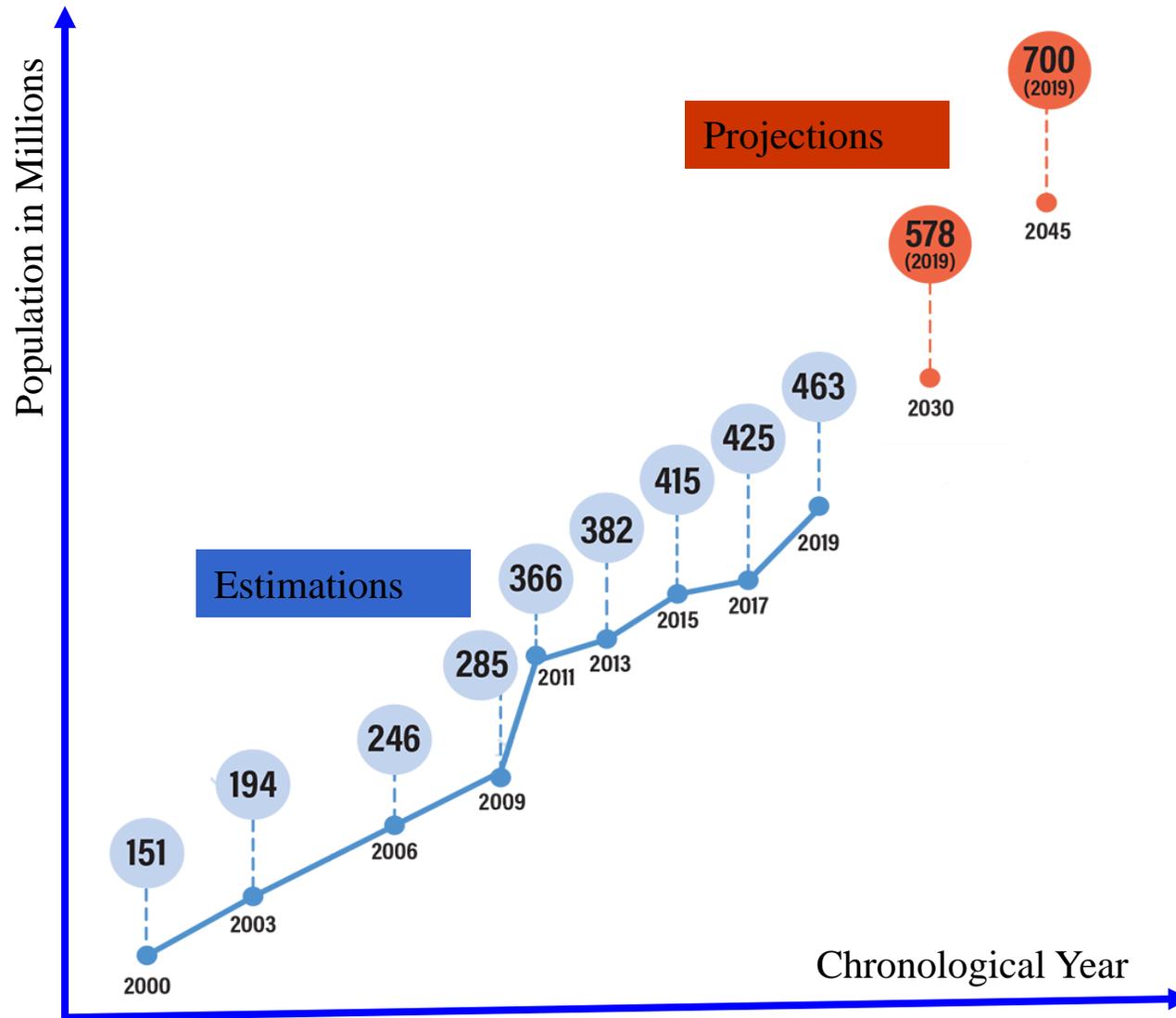
Good-Eye: Prototyping



Good-Eye: Fall detection and prediction Accuracy - 95%.

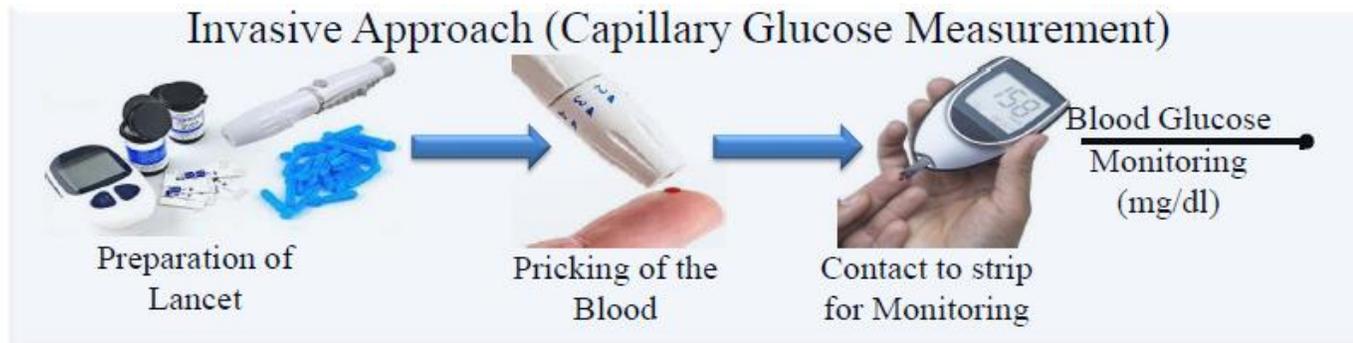
Source: L. Rachakonda, A. Sharma, S. P. Mohanty, and E. Kougianos, "Good-Eye: A Combined Computer-Vision and Physiological-Sensor based Device for Full-Proof Prediction and Detection of Fall of Adults", in *Proceedings of the 2nd IFIP International Internet of Things (IoT) Conference (IFIP-IoT)*, 2019, pp. 273--288.

Diabetes is a Global Crisis

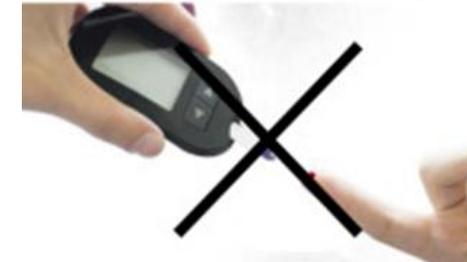


Source: A. M. Joshi, P. Jain and S. P. Mohanty, "Everything You Wanted to Know About Continuous Glucose Monitoring," *IEEE Consumer Electronics Magazine*, doi: 10.1109/MCE.2021.3073498.

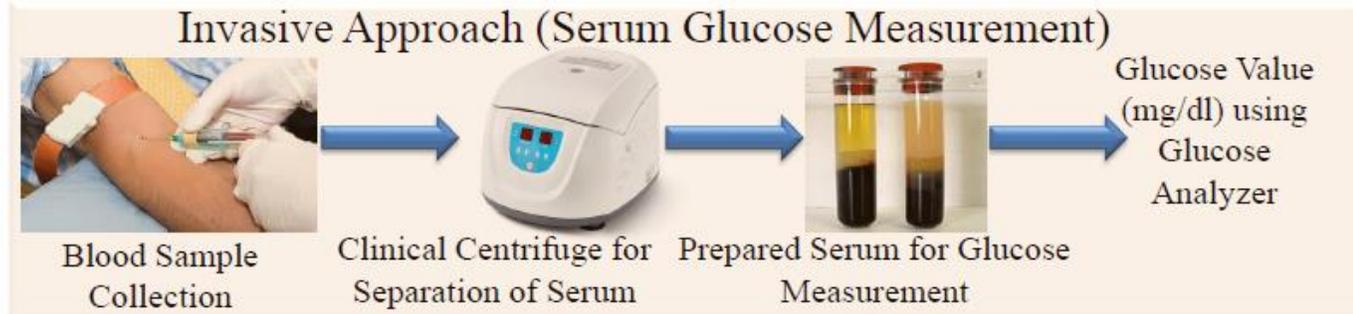
Blood Glucose Monitoring – Invasive Vs Noninvasive



Traditional – Finger Pricking



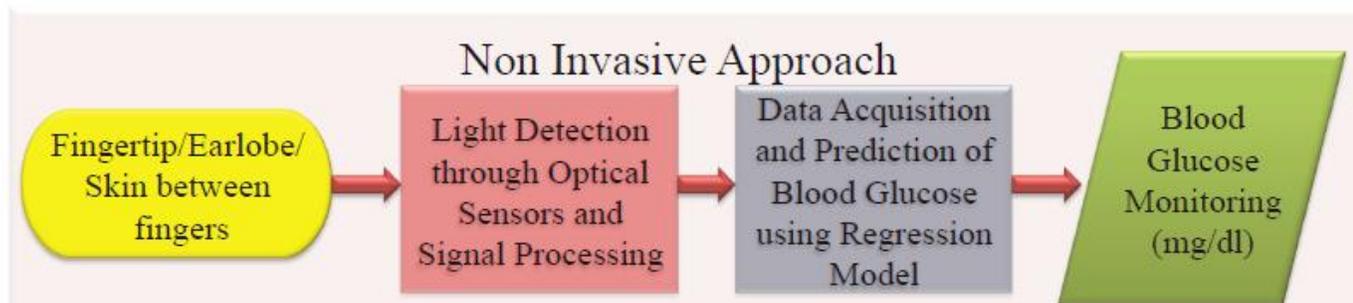
Invasive Approach – Processing Blood/Serum



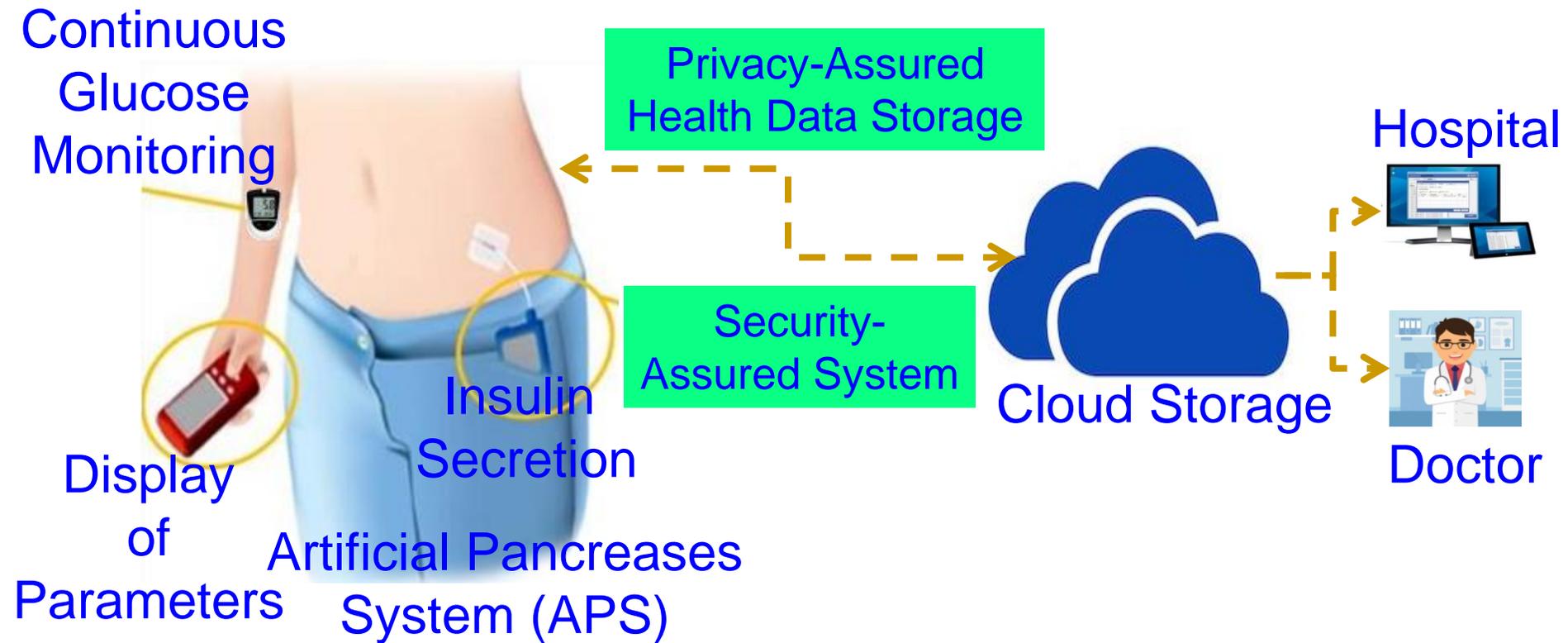
Noninvasive – Wearable



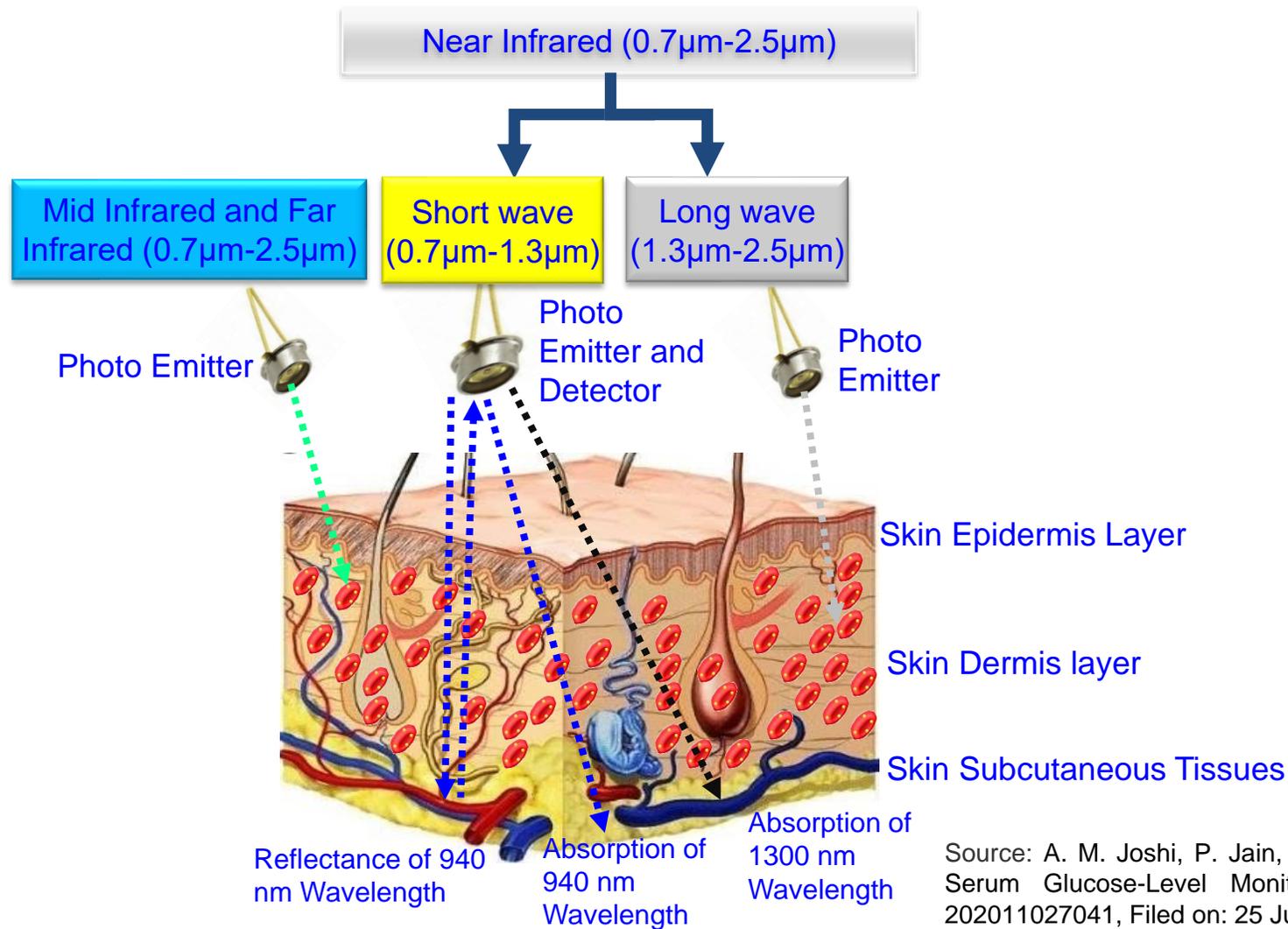
Noninvasive Approach – Processing Light



Automatic Glucose Monitoring and Control - Our Vision - iGLU (Intelligent Noninvasive)

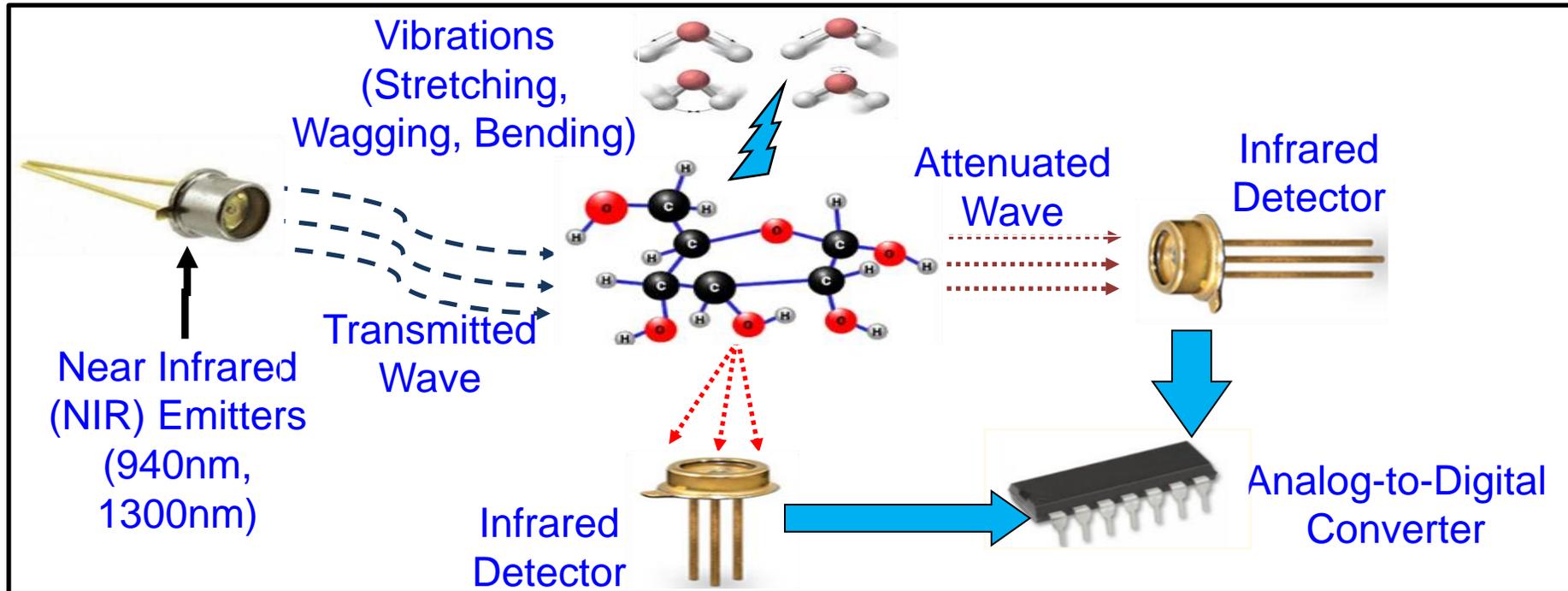


Unique Near Infrared Spectroscopy for iGLU



Source: A. M. Joshi, P. Jain, and S. P. Mohanty, A Device For Non-Invasive Blood and Serum Glucose-Level Monitoring and Control, India Patent Application Number: 202011027041, Filed on: 25 June 2020.

iGLU 1.0: Capillary Glucose



Clinically tested in an hospital.

Cost - US\$ 20
Accuracy - 100%

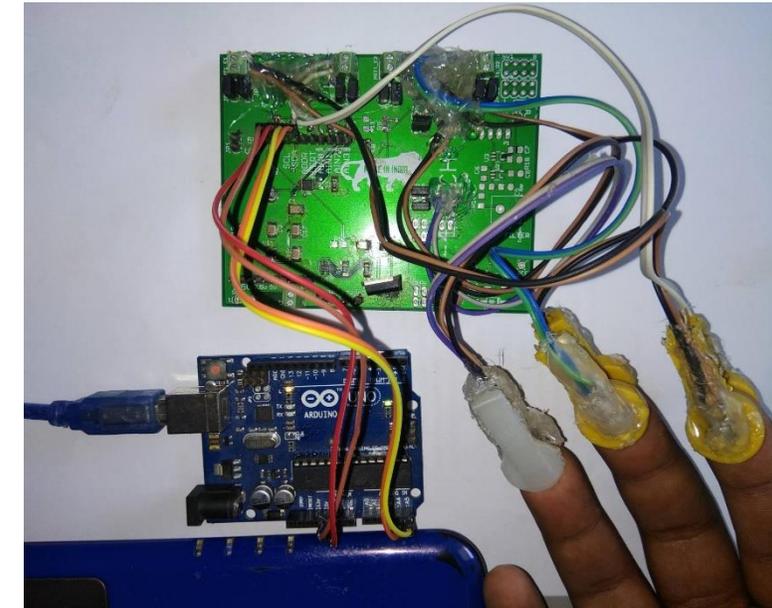
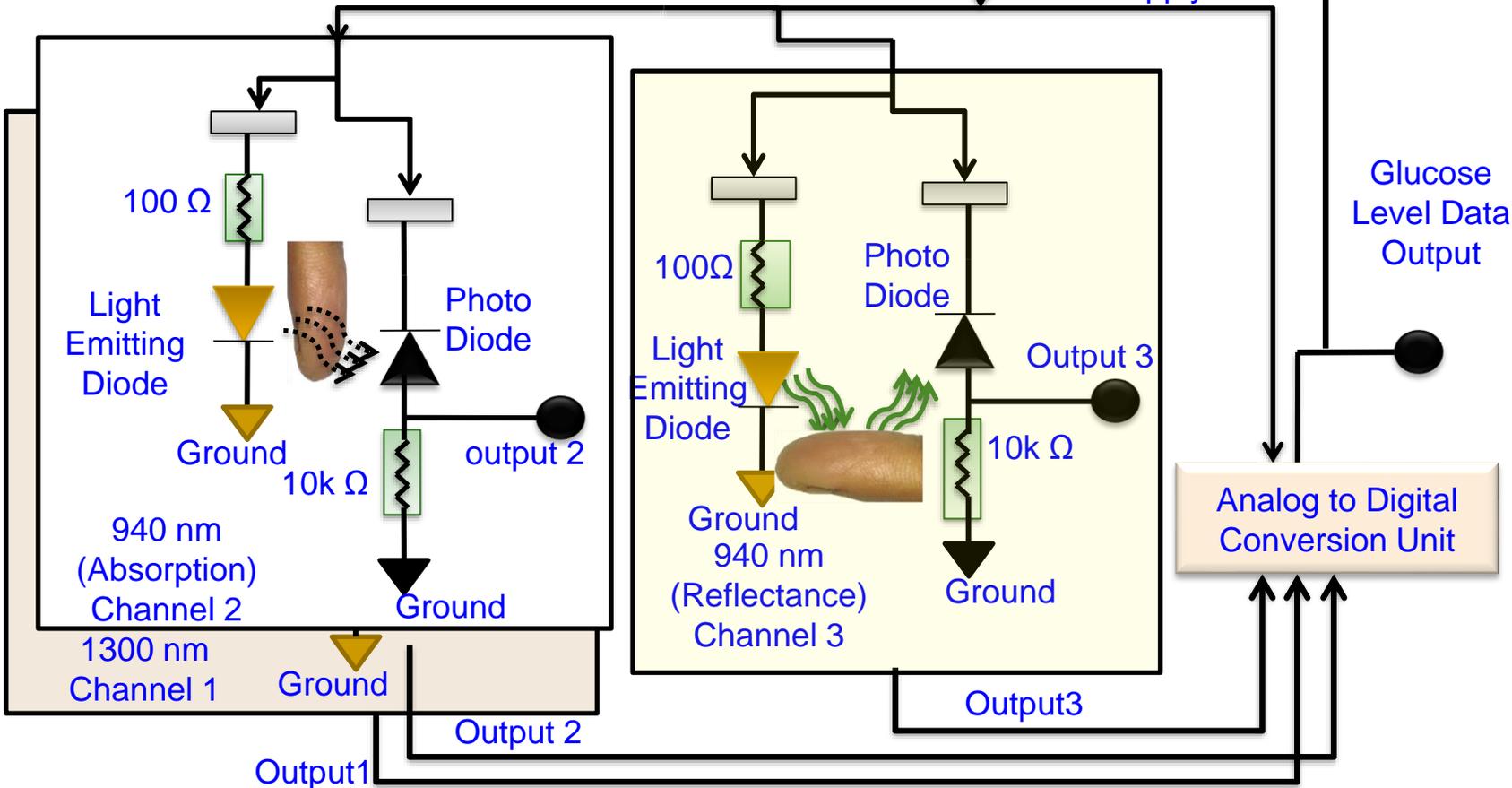
Source: P. Jain, A. M. Joshi, and S. P. Mohanty, "iGLU: An Intelligent Device for Accurate Non-Invasive Blood Glucose-Level Monitoring in Smart Healthcare", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 9, No. 1, January 2020, pp. 35-42.

iGLU – Design Implementation

Data logging for model training, validation and testing

Processing Unit

Power Supply

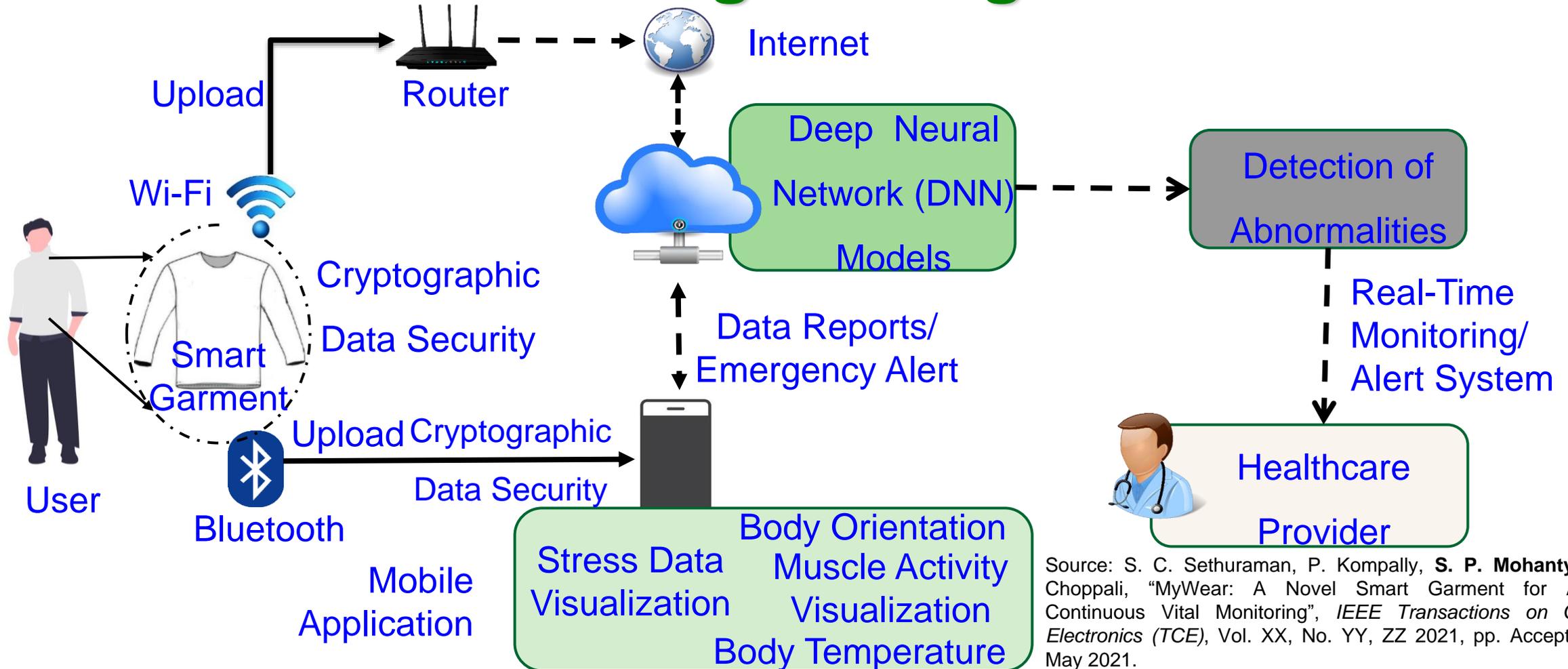


Clinically tested in an hospital.

Cost - US\$ 20
Accuracy - 100%

Source: A. M. Joshi, P. Jain, and S. P. Mohanty, A Device For Non-Invasive Blood and Serum Glucose-Level Monitoring and Control, India Patent Application Number: 202011027041, Filed on: 25 June 2020.

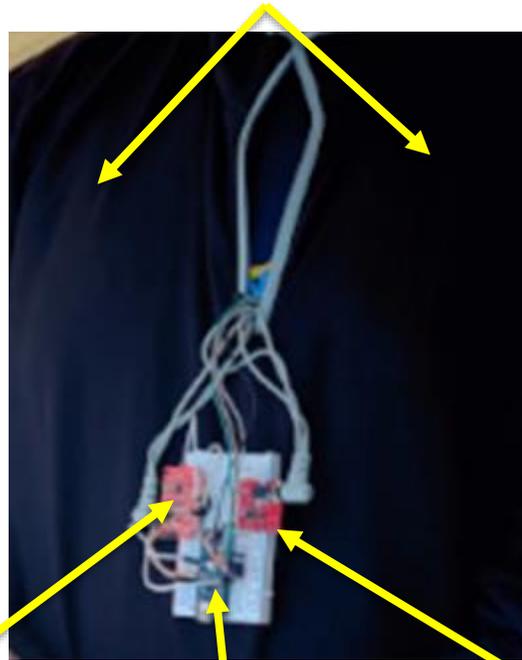
MyWear – A Smart Wear for Continuous Body Vital Monitoring – using ECG & EMG



Source: S. C. Sethuraman, P. Kompally, **S. P. Mohanty**, and U. Choppali, "MyWear: A Novel Smart Garment for Automatic Continuous Vital Monitoring", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. XX, No. YY, ZZ 2021, pp. Accepted on 30 May 2021.

MyWear – A Smart Wear for Continuous Body Vital Monitoring – using ECG & EMG

Embedded Electrodes inside MyWear



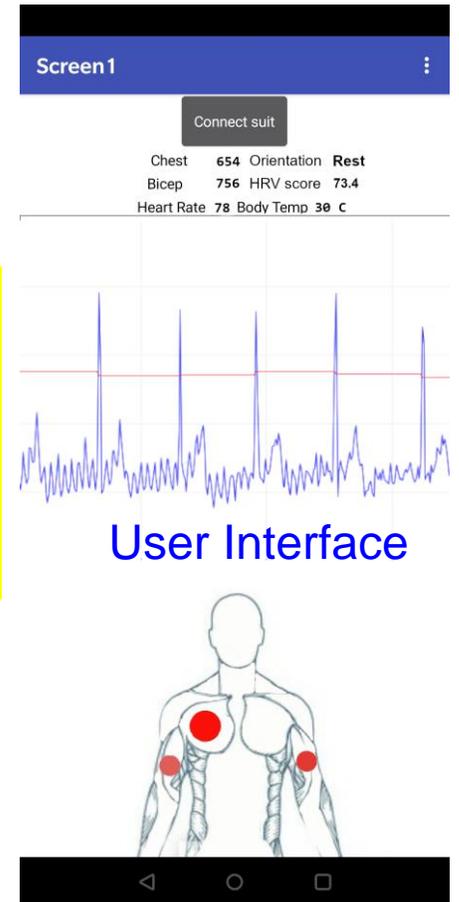
ECG Sensor

Micro-controller

EMG Sensor

MyWear Prototype Results:

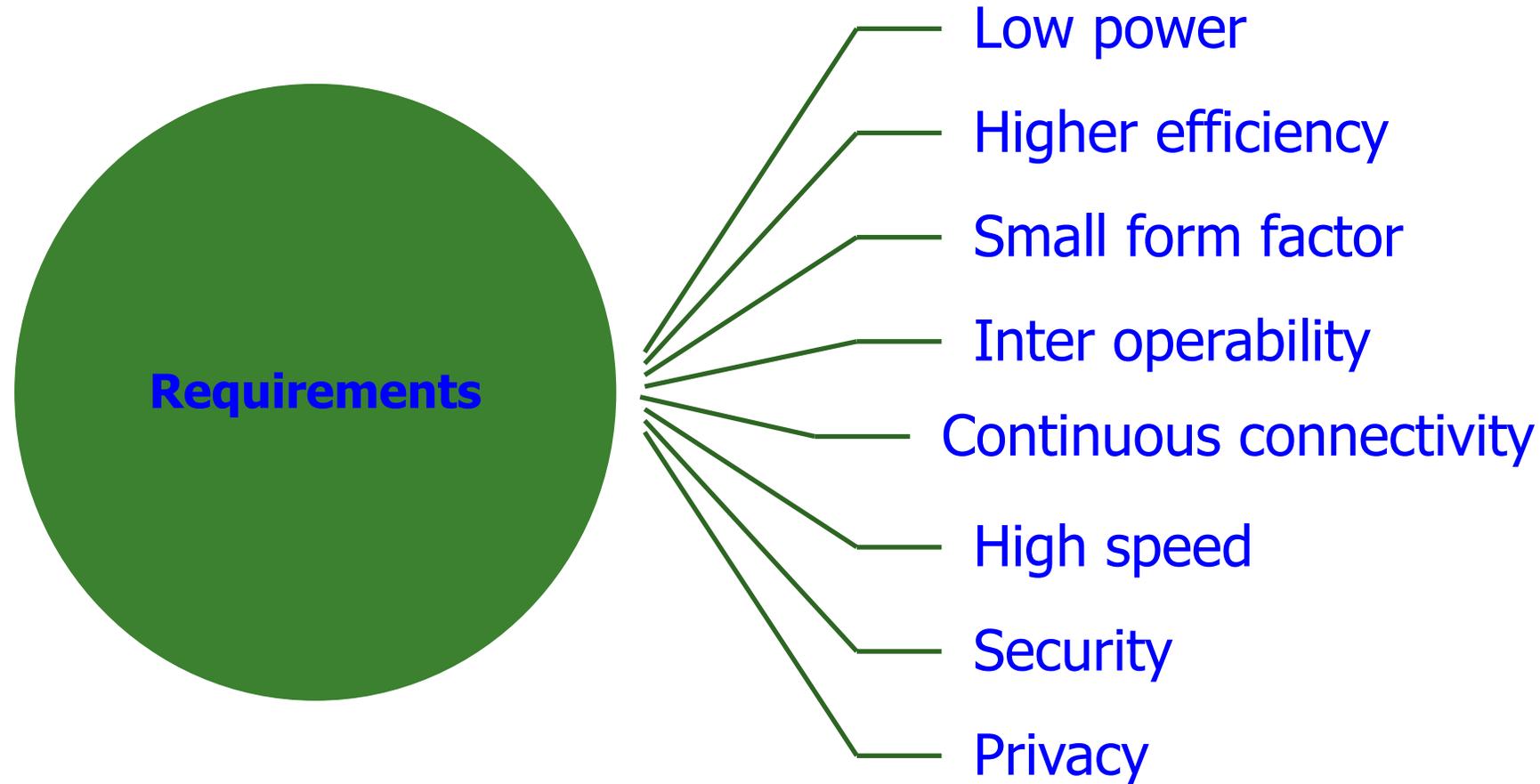
- Heartbeat Classification - Accuracy - 97%
- Myocardial Infarction (Heart Attack) - Accuracy - 98%
- Stress Level Detection - Accuracy - 97%
- Muscle Activity Detection - Accuracy - 96%
- Fall Detection - Accuracy - 98.5%



Source: S. C. Sethuraman, P. Kompally, **S. P. Mohanty**, and U. Choppali, "MyWear: A Novel Smart Garment for Automatic Continuous Vital Monitoring", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. XX, No. YY, ZZ 2021, pp. Accepted on 30 May 2021.

Smart Healthcare – Some Challenges

Smart Healthcare Architecture – Requirements



Smart Healthcare – Data Quality



Source: H. Zhu, C. K. Wu, C. H. KOO, Y. T. Tsang, Y.Liu, H. R. Chi, and K. F. Tsang, "Smart Healthcare in the Era of Internet-of-Things", *IEEE Consumer Electronics Magazine*, vol. 8, no. 5, pp. 26-30, Sep 2019.

Machine Learning Challenges



Machine Learning Issues



High Energy Requirements

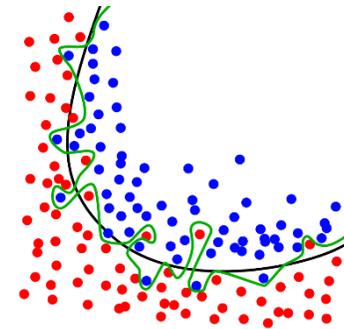
High Computational Resource Requirements

Large Amount of Data Requirements

Underfitting/Overfitting Issue

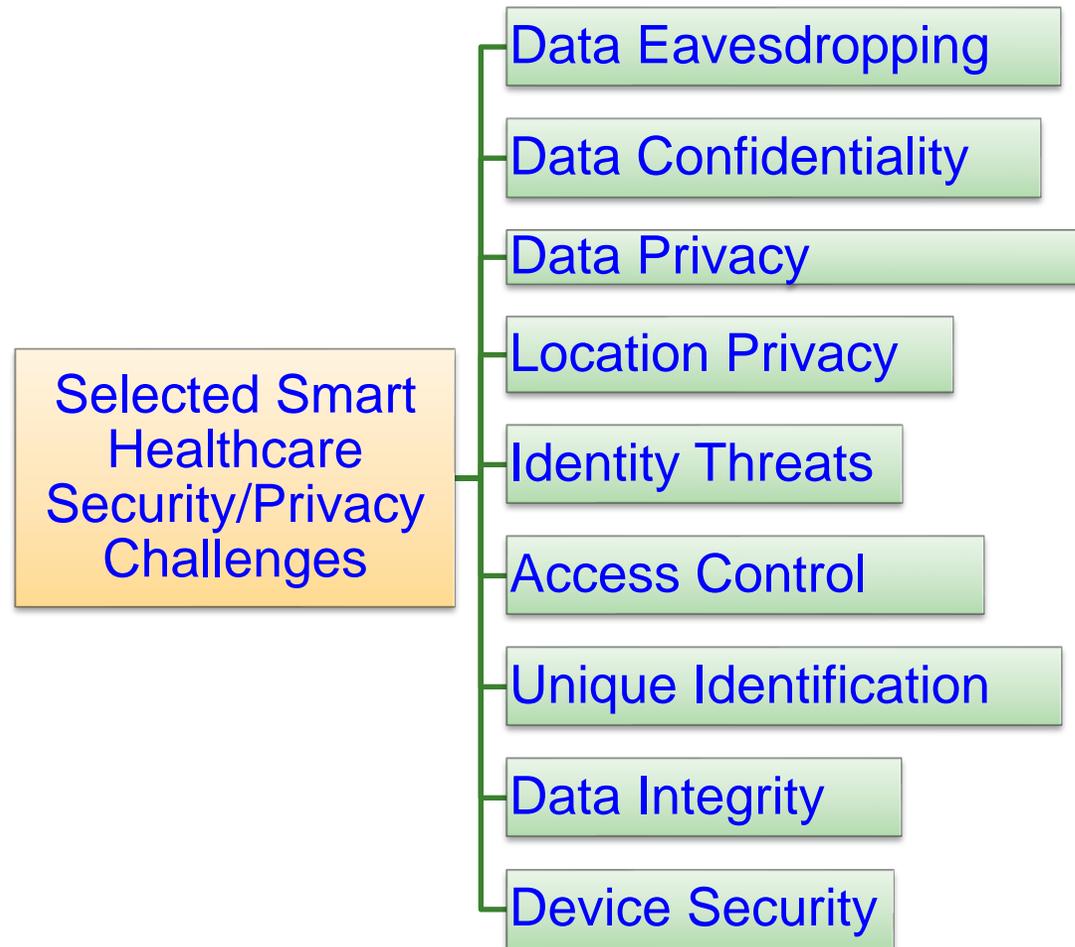
Class Imbalance Issue

Fake Data Issue



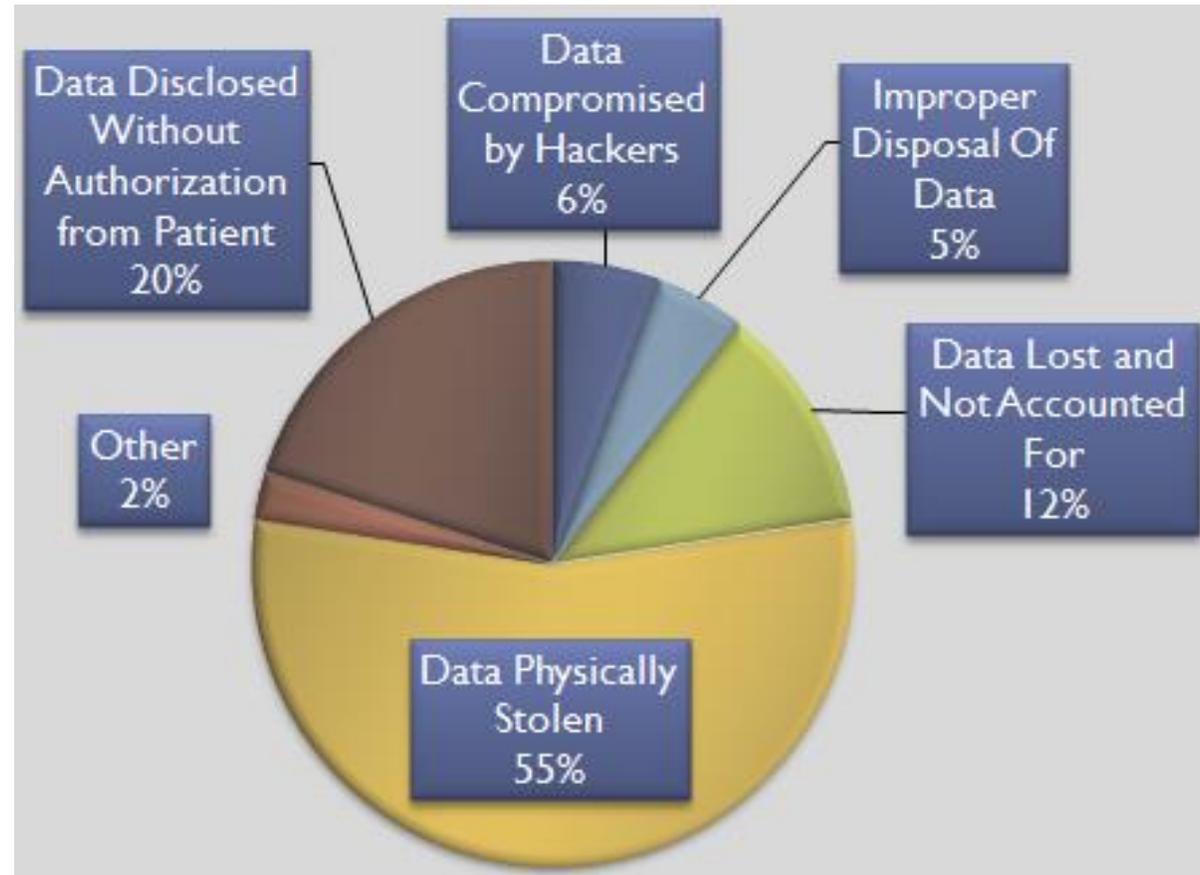
Source: Mohanty ISCT Keynote 2019

Smart Healthcare - Security Challenges



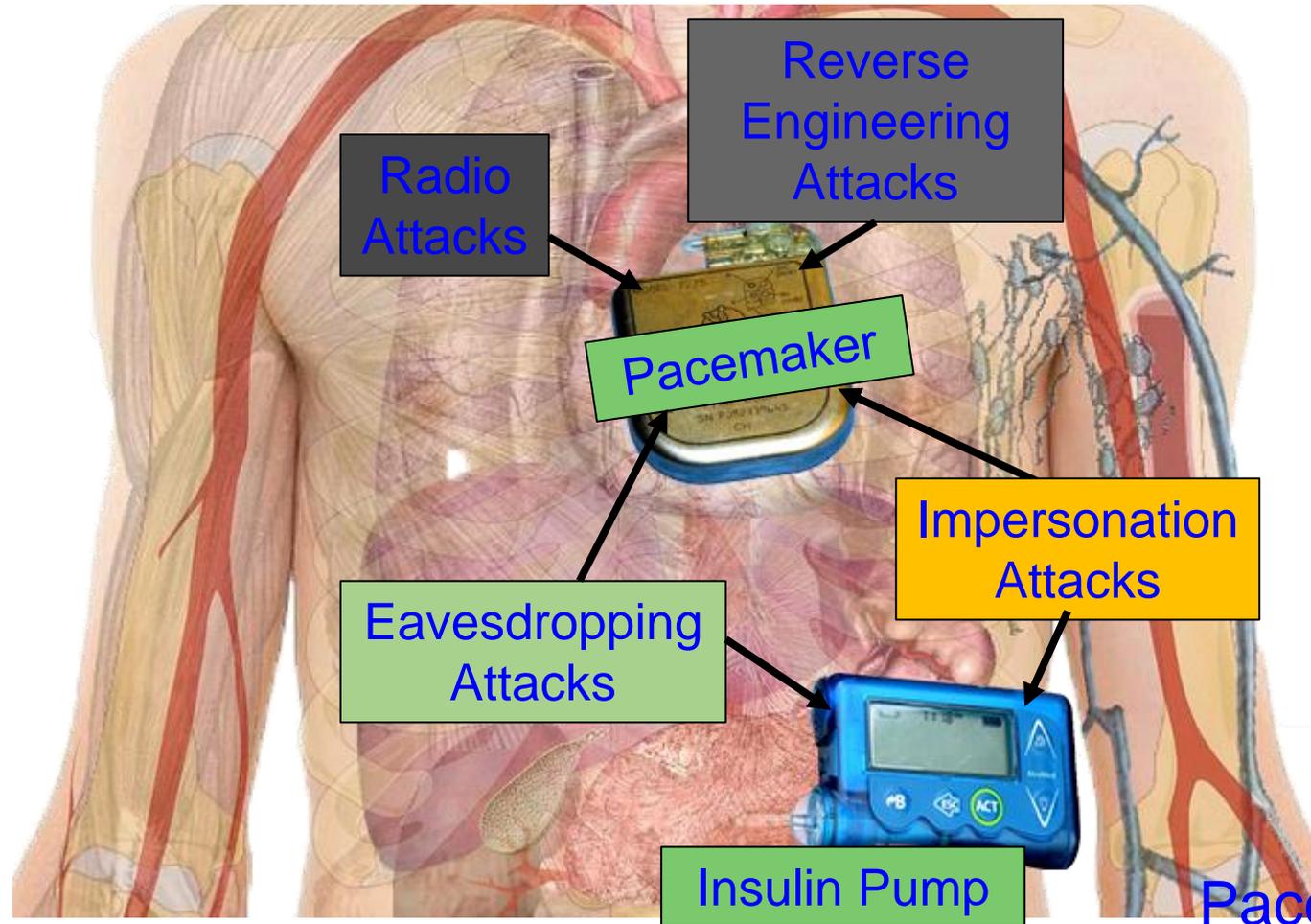
Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 1, January 2018, pp. 18-28.

Health Insurance Portability and Accountability Act (HIPAA)



HIPPA Privacy Violation by Types

IoMT Security Measures is Hard – Resource Constrained

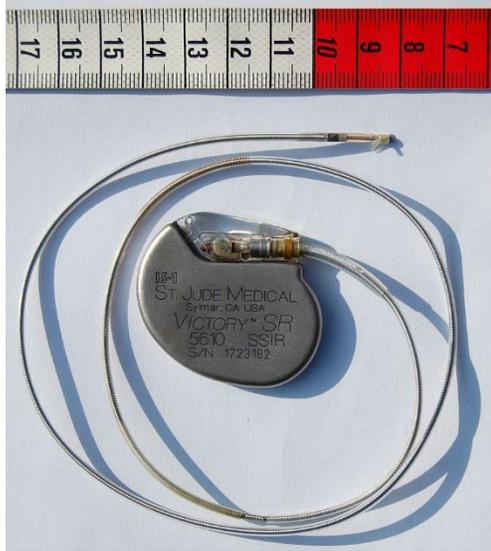


Collectively (WMD+IMD):
Implantable and Wearable
Medical Devices (IWMDs)

Implantable and Wearable
Medical Devices (IWMDs) --
Battery Characteristics:
→ Longer life
→ Safer
→ Smaller size
→ Smaller weight

Pacemaker Battery Life - 10 years

IoMT Security Measures is Hard – Energy Constrained



Pacemaker
Battery Life
- 10 years



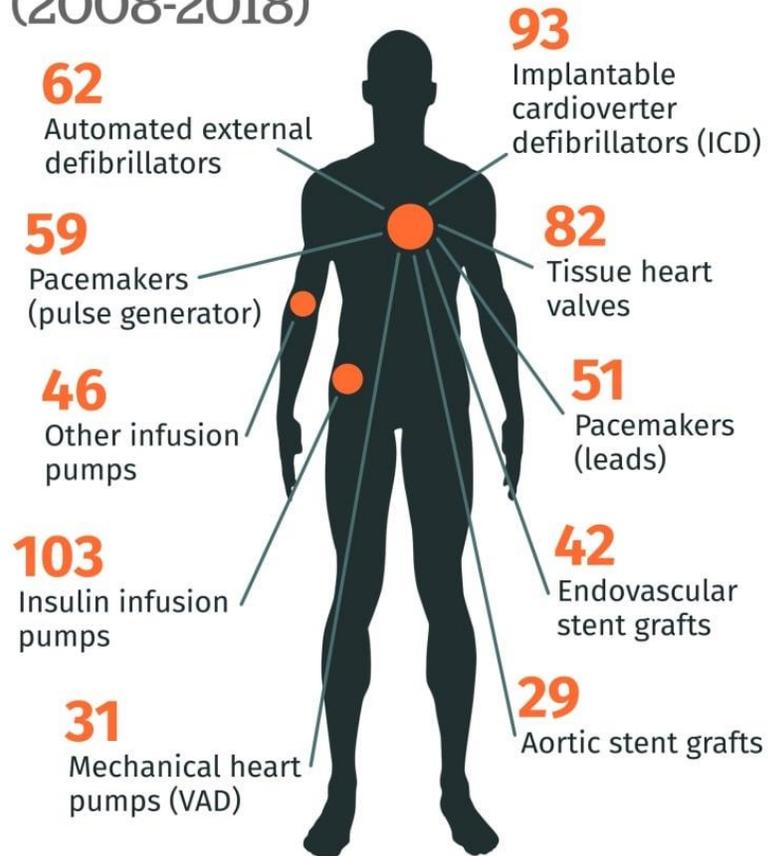
Neurostimulator
Battery Life
- 8 years

- Implantable Medical Devices (IMDs) have integrated battery to provide energy to all their functions → Limited Battery Life depending on functions
- Higher battery/energy usage → Lower IMD lifetime
- Battery/IMD replacement → Needs surgical risky procedures

Source: Carmen Camara, PedroPeris-Lopez, and Juan E.Tapiadora, "Security and privacy issues in implantable medical devices: A comprehensive survey", *Elsevier Journal of Biomedical Informatics*, Volume 55, June 2015, Pages 272-289.

Smart Healthcare - Safety

10 devices tied to the most reports involving death (2008-2018)



CBC NEWS

Source: Health Canada & ICIJ

Source <https://planet-report.com/canadian-advocates-call-for-all-medical-implants-to-be-registered-cbc-news/>

CENTRAL ILLUSTRATION: Cardiac-Implantable Electronic Devices: Technical and Safety Considerations

FACTORS INFLUENCING SAFETY	SMALL POTENTIAL RISKS
MR magnet: <ul style="list-style-type: none"> Magnet strength Radiofrequency power Magnet position 	Heating effects: <ul style="list-style-type: none"> Tissue injury (Mainly theoretical) Strategy to minimize risk: Lead designed to limit current induction
Cardiac implantable device: <ul style="list-style-type: none"> Ferromagnetic material Presence of reed switch Device programming 	Mechanical effects: <ul style="list-style-type: none"> Device movement (Mainly theoretical) Strategy to minimize risk: Limitation of ferromagnetic materials
Leads: <ul style="list-style-type: none"> Ferromagnetic material Lead stability 	Electromagnetic effects: <ul style="list-style-type: none"> Altered sensing/capture Inhibited therapies Inappropriate therapies (No significant adverse patient outcomes) Strategy to minimize risk: Lead designed to limit current induction, replacement of reed switch with Hall sensor, temporary device reprogramming
Patient: <ul style="list-style-type: none"> Patient position Patient size 	
Indication to scan: If the benefits outweigh the very small potential risks, MRI is acceptable	

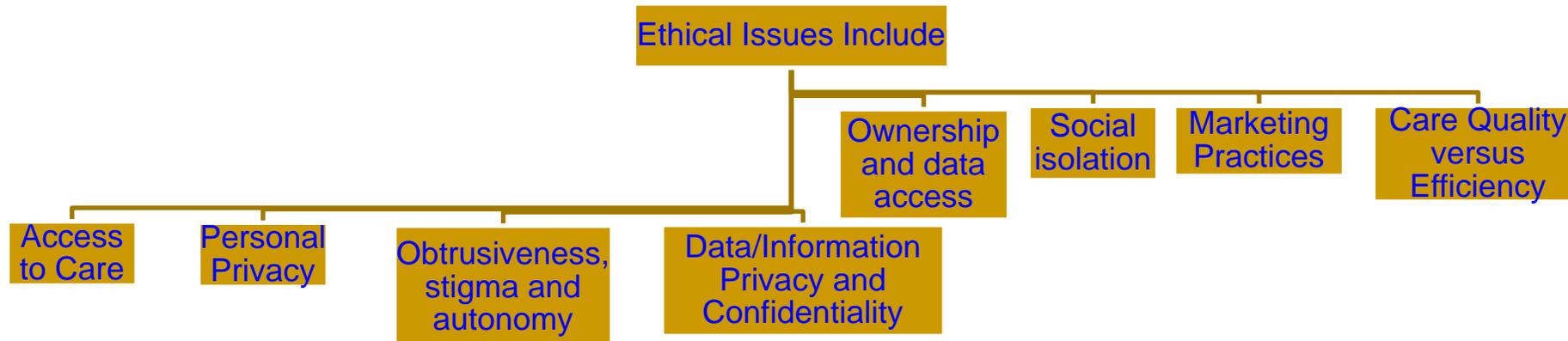
Miller, J.D. et al. J Am Coll Cardiol. 2016;68(14):1590-8.

Source: J. D. Miller, S. Nazarian, H. R. Halperin, "Implantable Electronic Cardiac Devices and Compatibility With Magnetic Resonance Imaging", J Am Coll Cardiol. 2016 Oct, 68 (14), pp. 1590-1598.

Smart Healthcare - Ethics



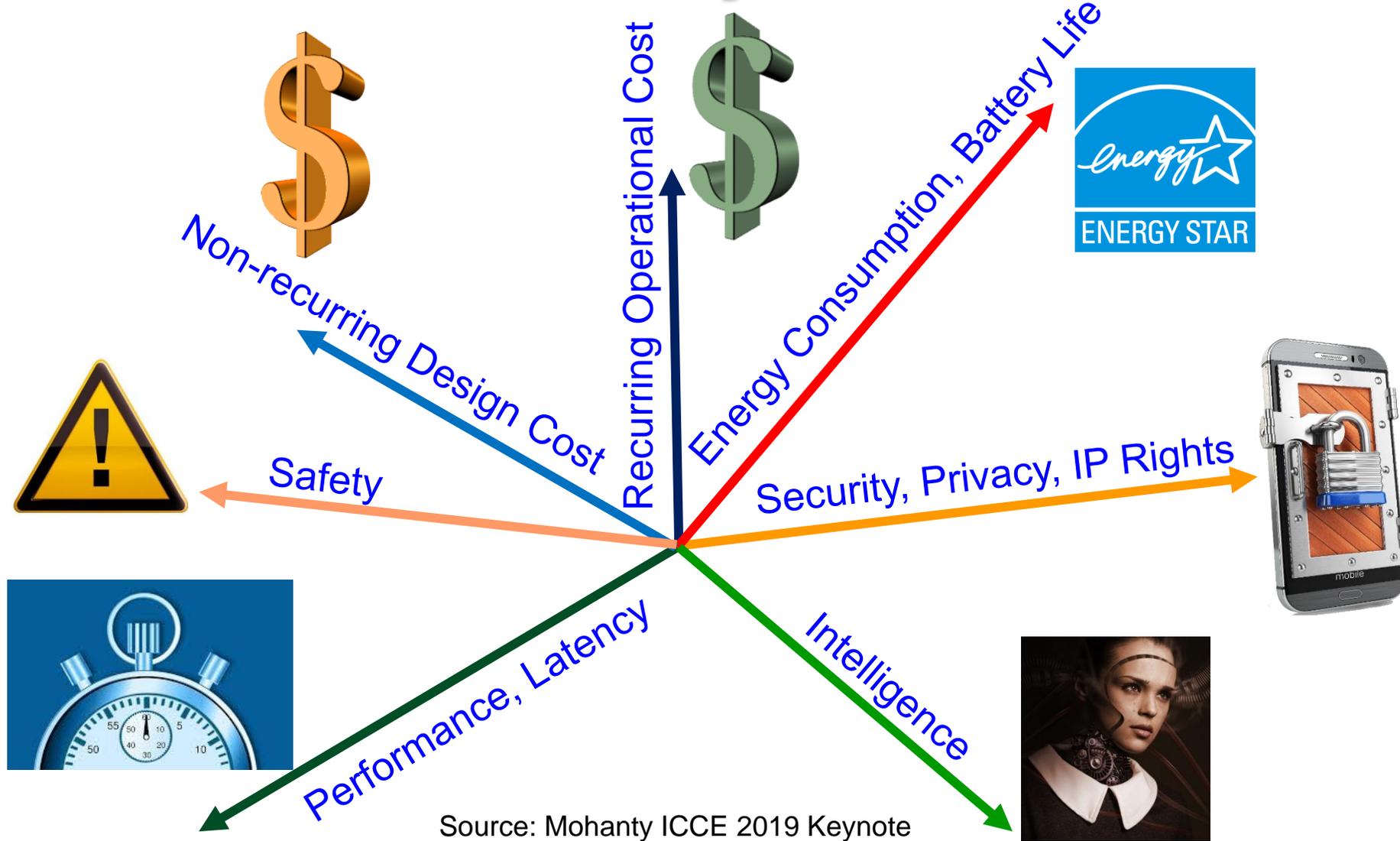
Source: <https://online.alvernia.edu/articles/ethical-issues-in-healthcare/>



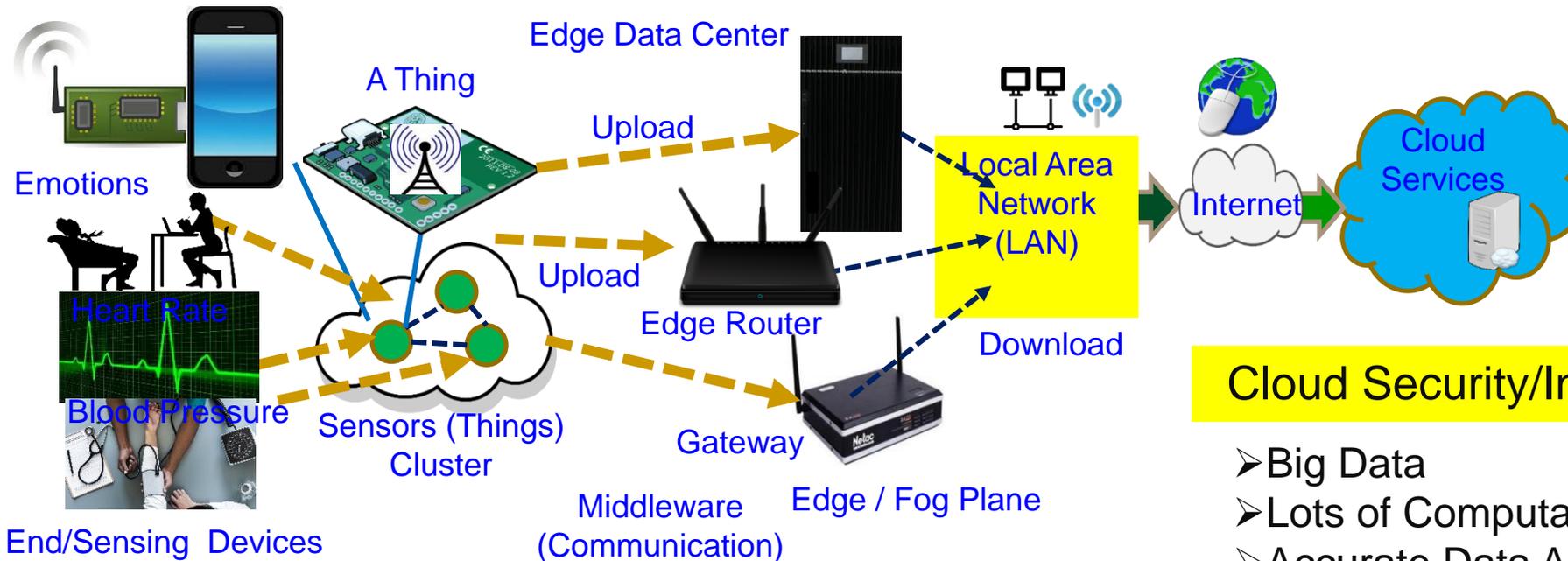
Source: B. Mittelstadt, "Ethics of the health-related internet of things: a narrative review", *Ethics Inf Technol* **19**, 157–175 (2017), DOI: <https://doi.org/10.1007/s10676-017-9426-4>.

Smart Healthcare – Some Solutions

H-CPS - Multi-Objective Tradeoffs



Smart Healthcare – Edge Vs Cloud



End Security/Intelligence

- Minimal Data
- Minimal Computational Resource
- Least Accurate Data Analytics
- Very Rapid Response

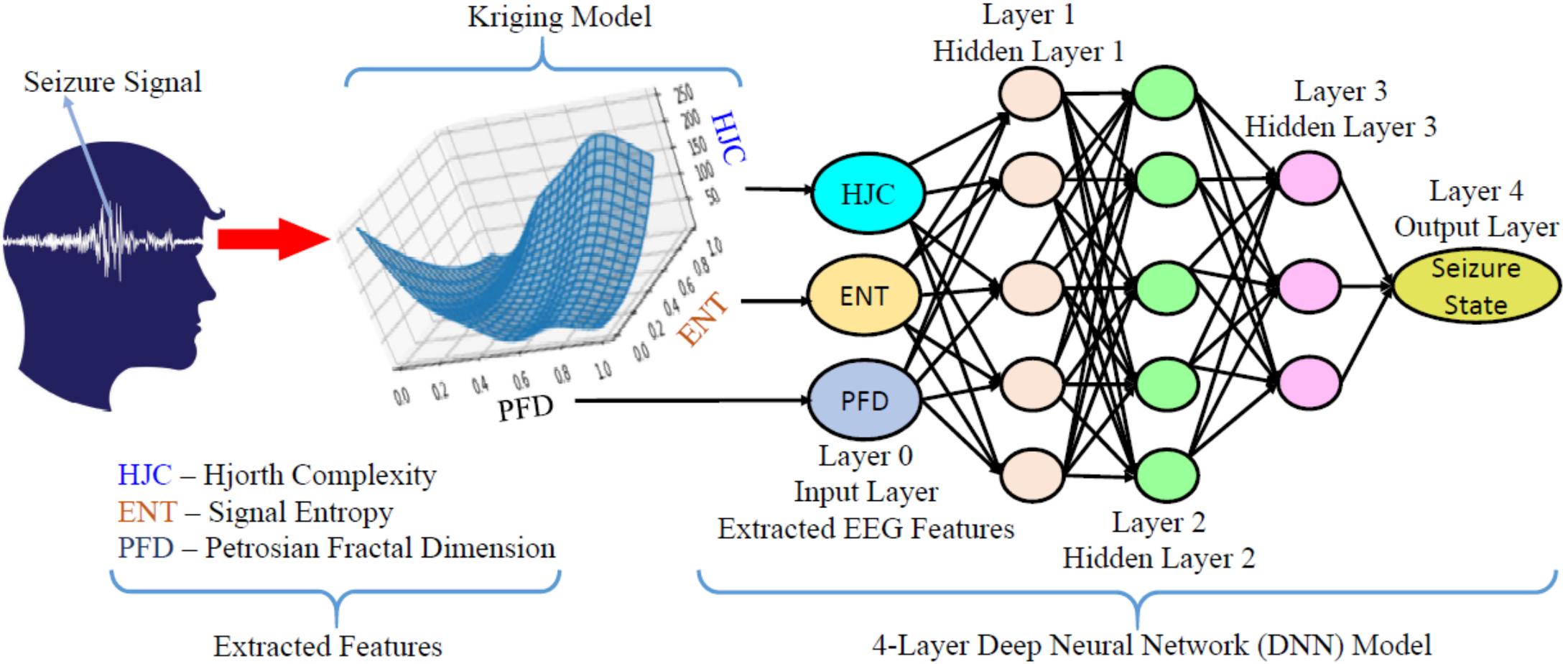
Edge Security/Intelligence

- Less Data
- Less Computational Resource
- Less Accurate Data Analytics
- Rapid Response

Cloud Security/Intelligence

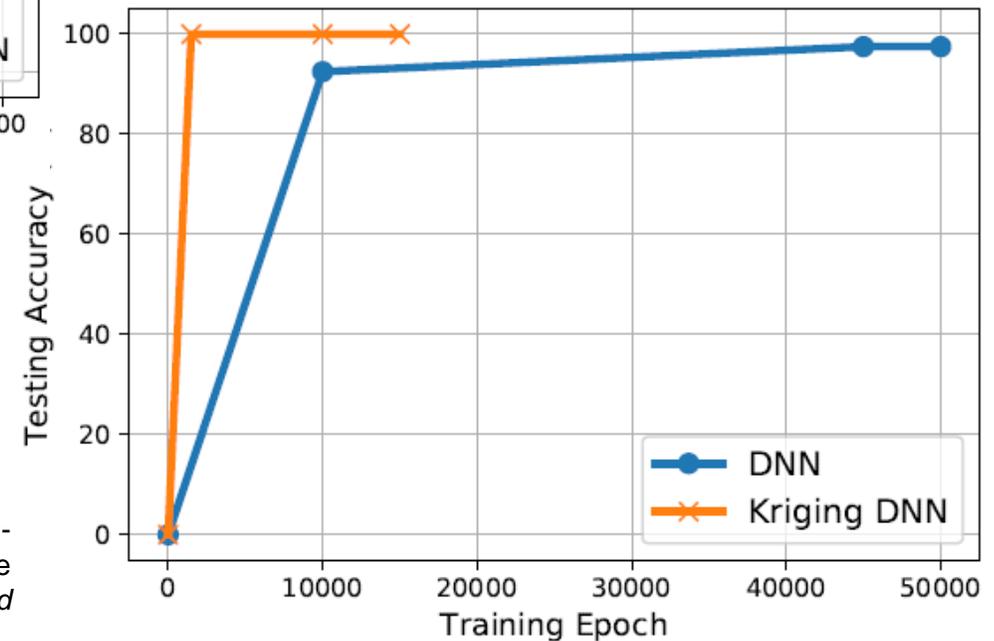
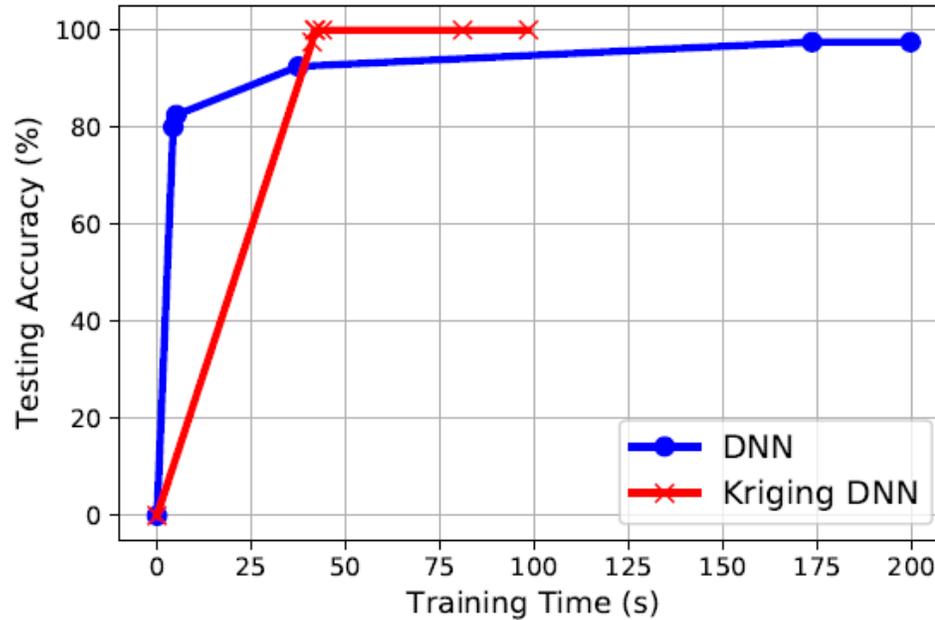
- Big Data
- Lots of Computational Resource
- Accurate Data Analytics
- Latency in Network
- Energy overhead in Communications

Our Kriging-Bootstrapped DNN Model



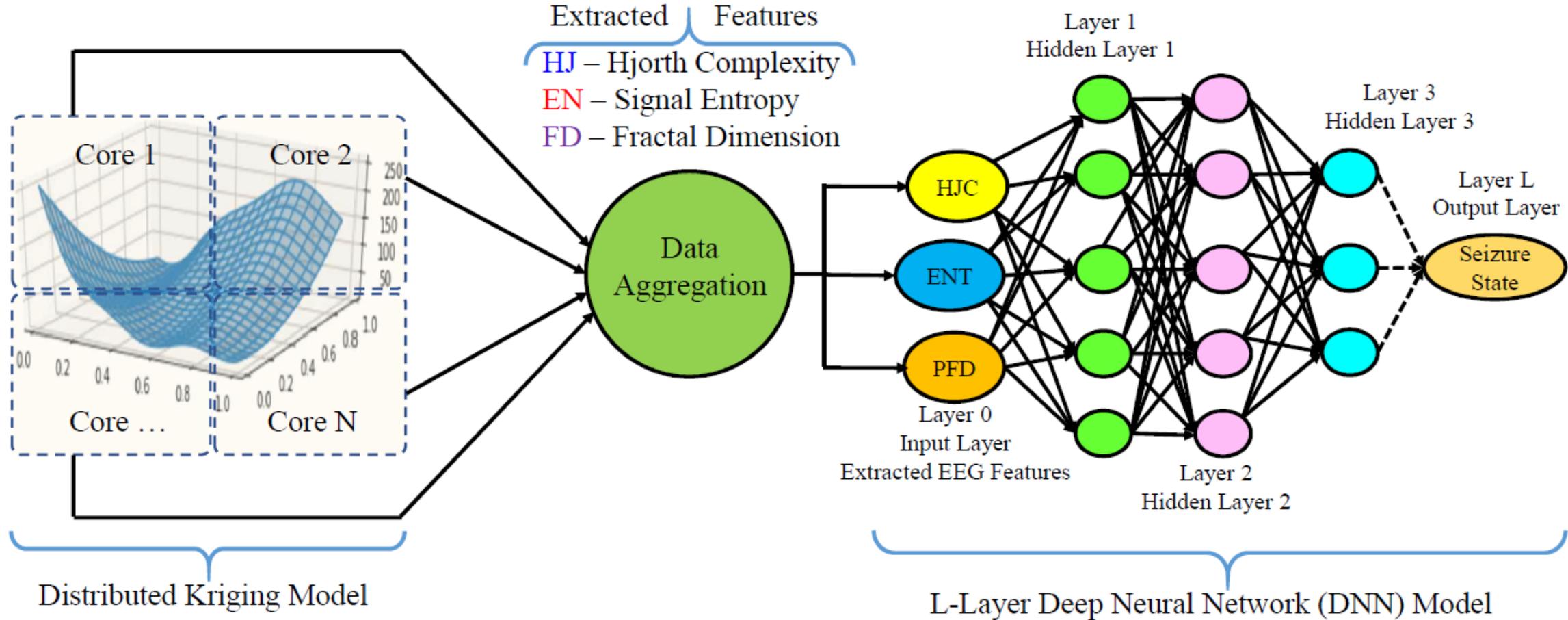
Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Kriging-Bootstrapped DNN Hierarchical Model for Real-Time Seizure Detection from EEG Signals", in *Proceedings of the 6th IEEE World Forum on Internet of Things (WF-IoT)*, 2020

Experimental Results



Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Kriging-Bootstrapped DNN Hierarchical Model for Real-Time Seizure Detection from EEG Signals", in *Proceedings of the 6th IEEE World Forum on Internet of Things (WF-IoT)*, 2020

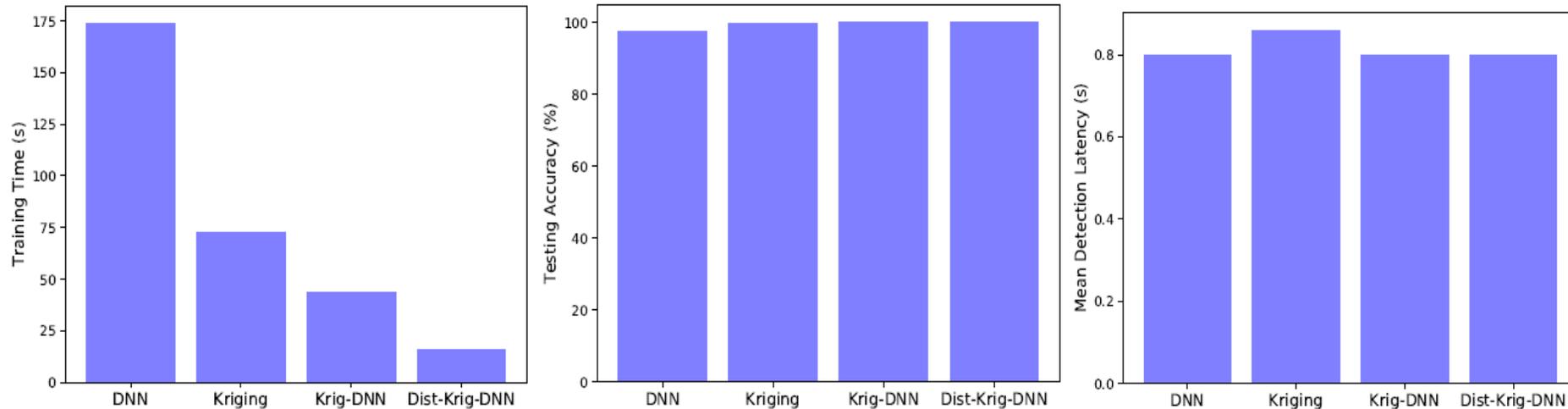
Our Distributed Kriging-Bootstrapped DNN Model



Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Distributed Kriging-Bootstrapped DNN Model for Fast, Accurate Seizure Detection from EEG Signals", *Proceedings of the 19th IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 2020.

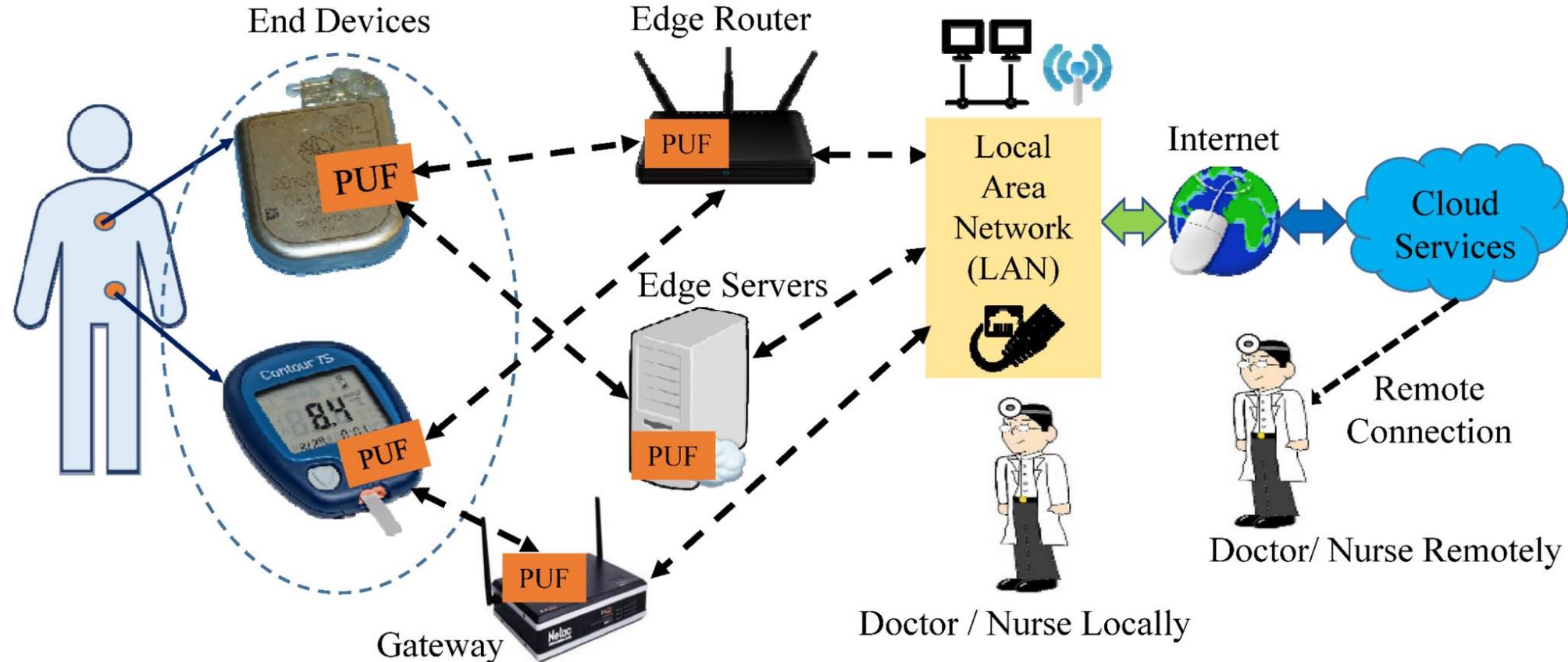
Experimental Results: Dataset A

Models	Detection Latency
DNN	0.80s
Ordinary Kriging	0.86s
Krig-DNN	0.80s
Dist-Krig-DNN	0.80s



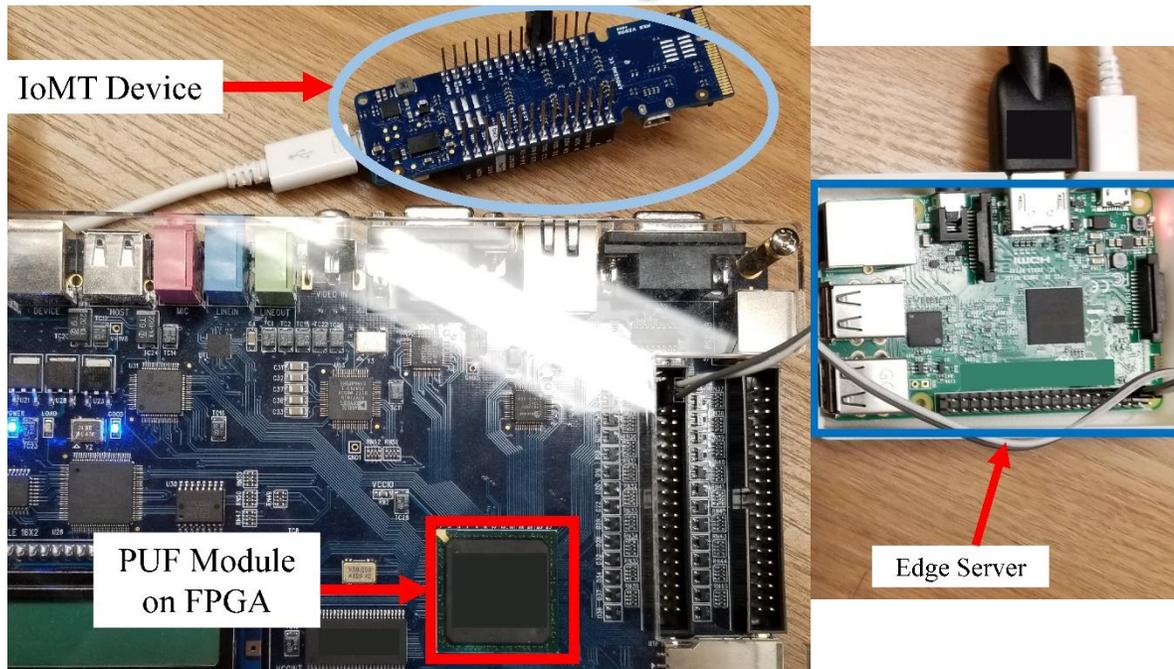
Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Distributed Kriging-Bootstrapped DNN Model for Fast, Accurate Seizure Detection from EEG Signals", *Proceedings of the 19th IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 2020.

Our Secure by Design Approach for Robust Security in Healthcare CPS



Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, "PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

IoMT Security – Our Proposed PMsec

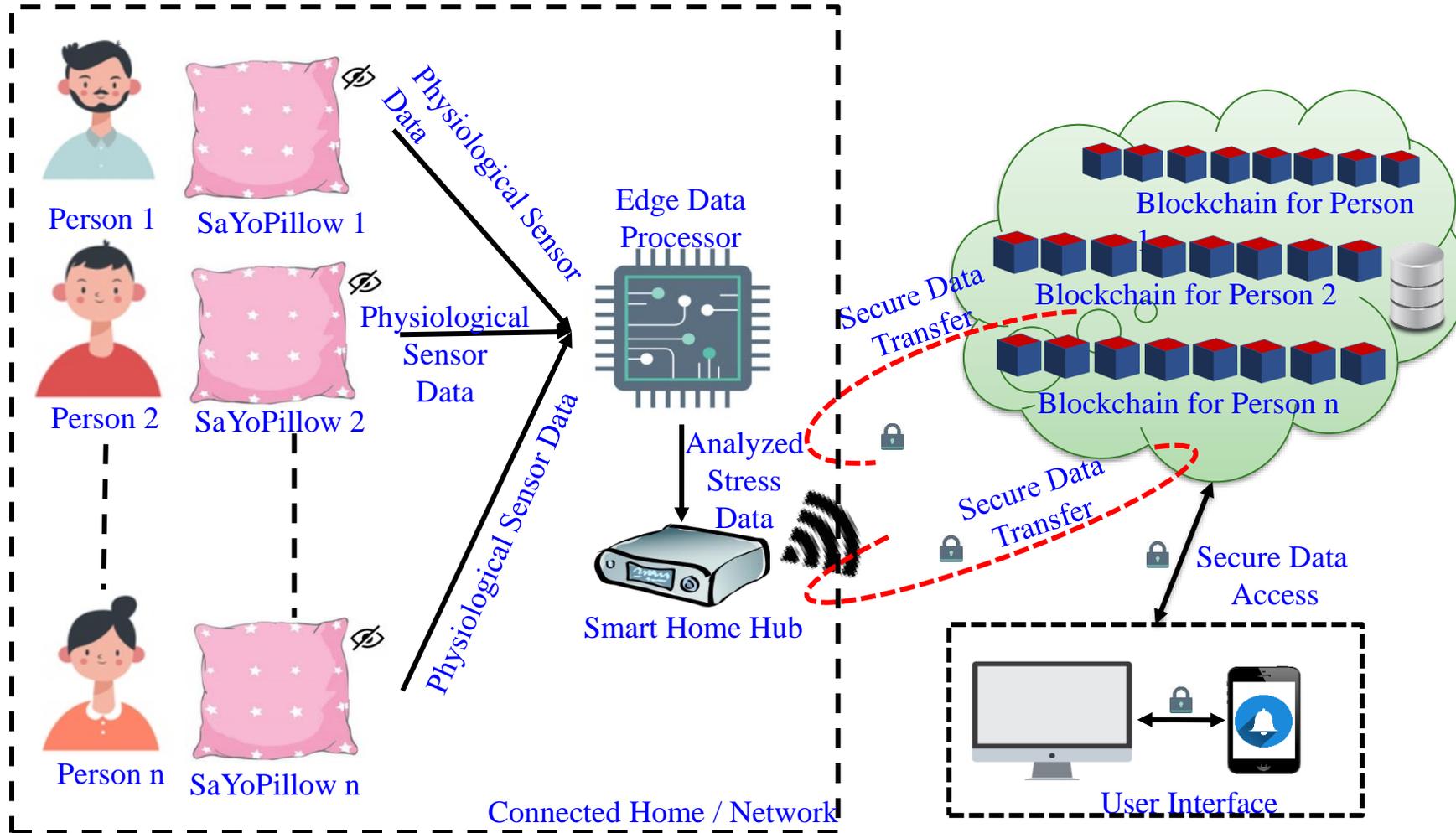


Average Power Overhead –
~ 200 μ W or 0.2 mW

Proposed Approach Characteristics	Value (in a FPGA / Raspberry Pi Platform)
Time to Generate the Key at Server	800 ms
Time to Generate the Key at IoMT Device	800 ms
Time to Authenticate the Device	1.2 sec - 1.5 sec

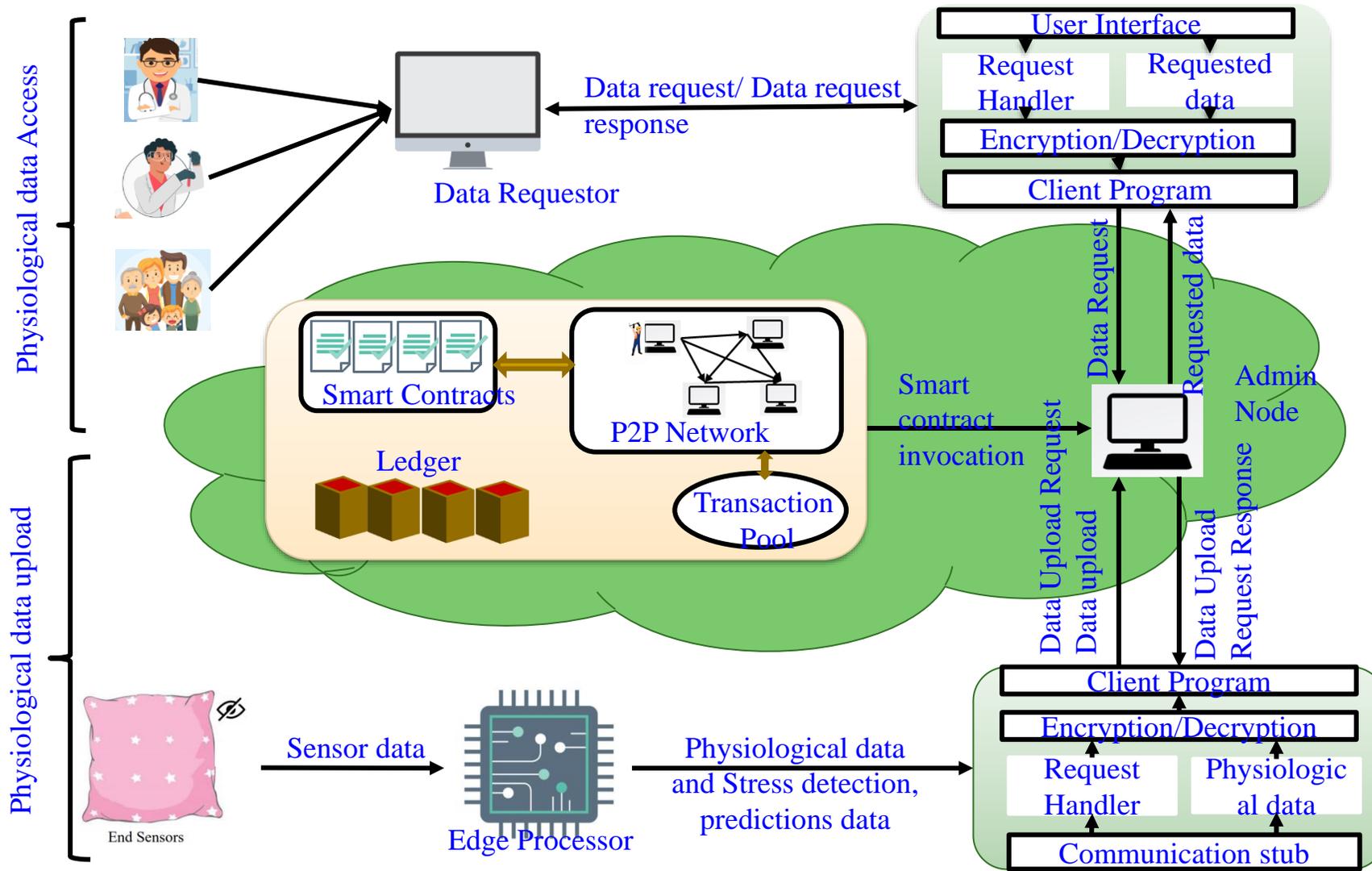
Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, “PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things”, *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

Our Smart-Yoga Pillow (SaYoPillow)



Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

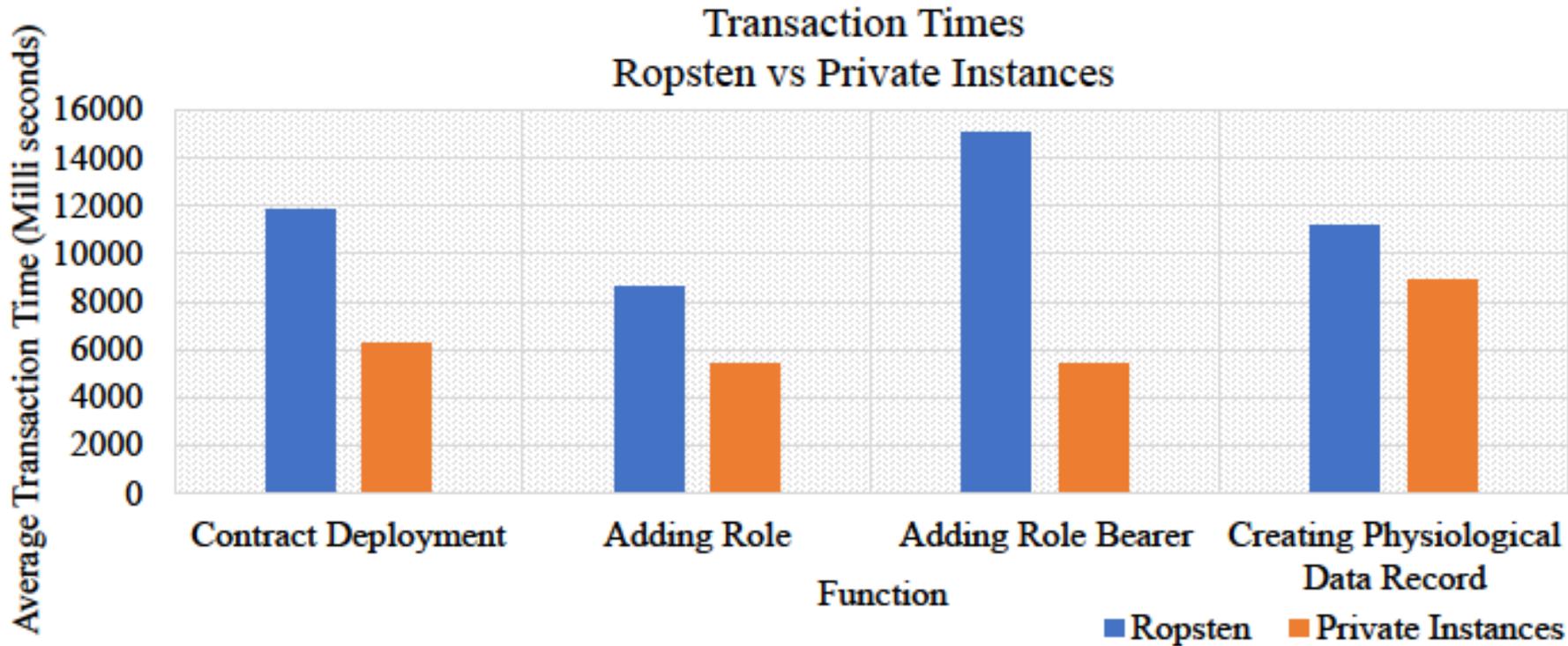
SaYoPillow: Blockchain Details



Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

SaYoPillow: Prototyping

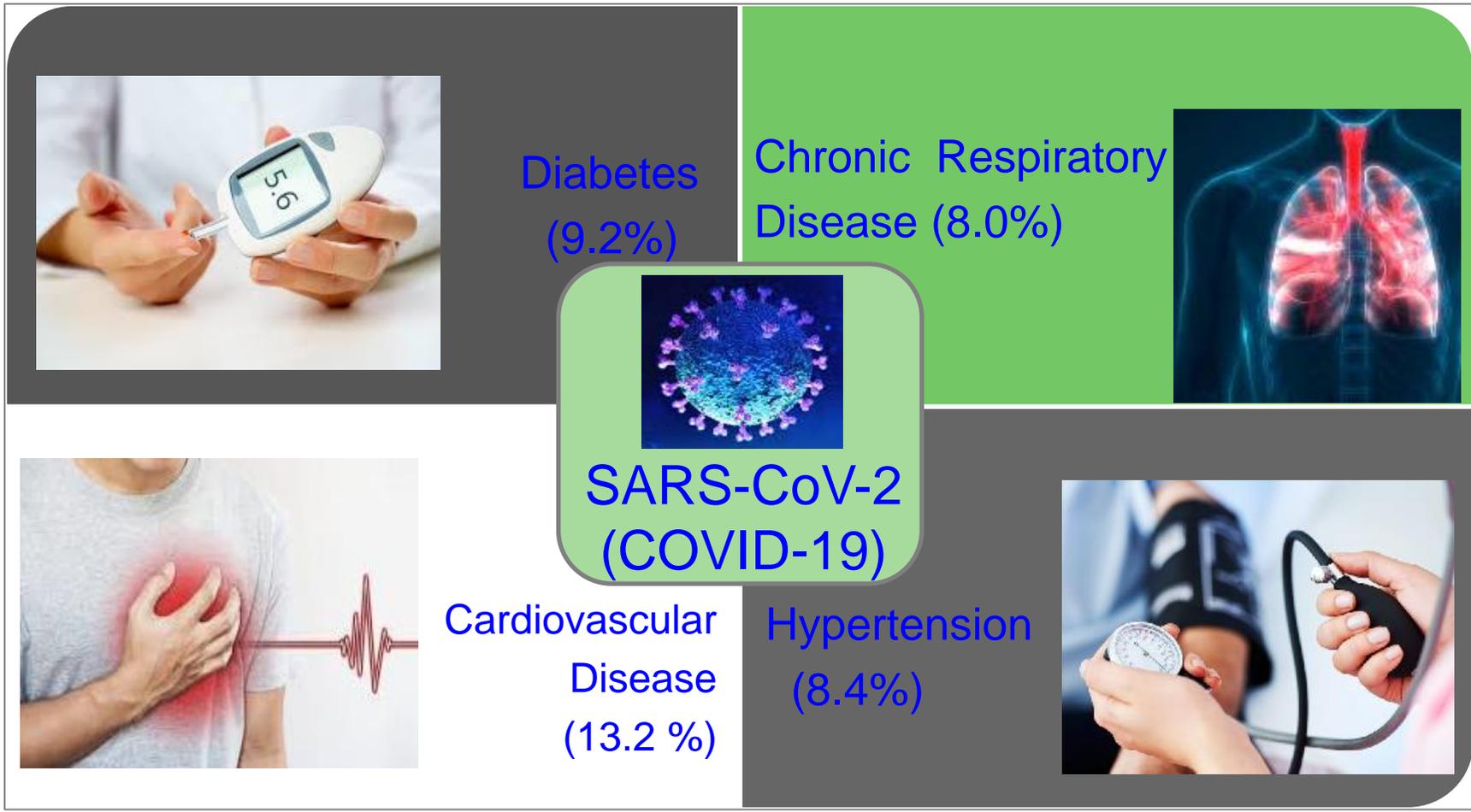
Network	Contract Deployment: Min, Max and Avg TT (secs)			Adding Role: Min, Max and Avg TT (secs)			Adding Role Bearer: Min, Max and Avg TT (secs)			Creating Data Record: Min, Max and Avg TT (secs)		
Ropsten	3.29	26.75	11.8	1.2	18.4	8.6	1.4	35	15	1.5	38.2	11.2
SaYoPillow	3.2	13.5	6.3	1.4	10.7	5.4	1.5	14.2	5.4	2.2	11.5	8.9



Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

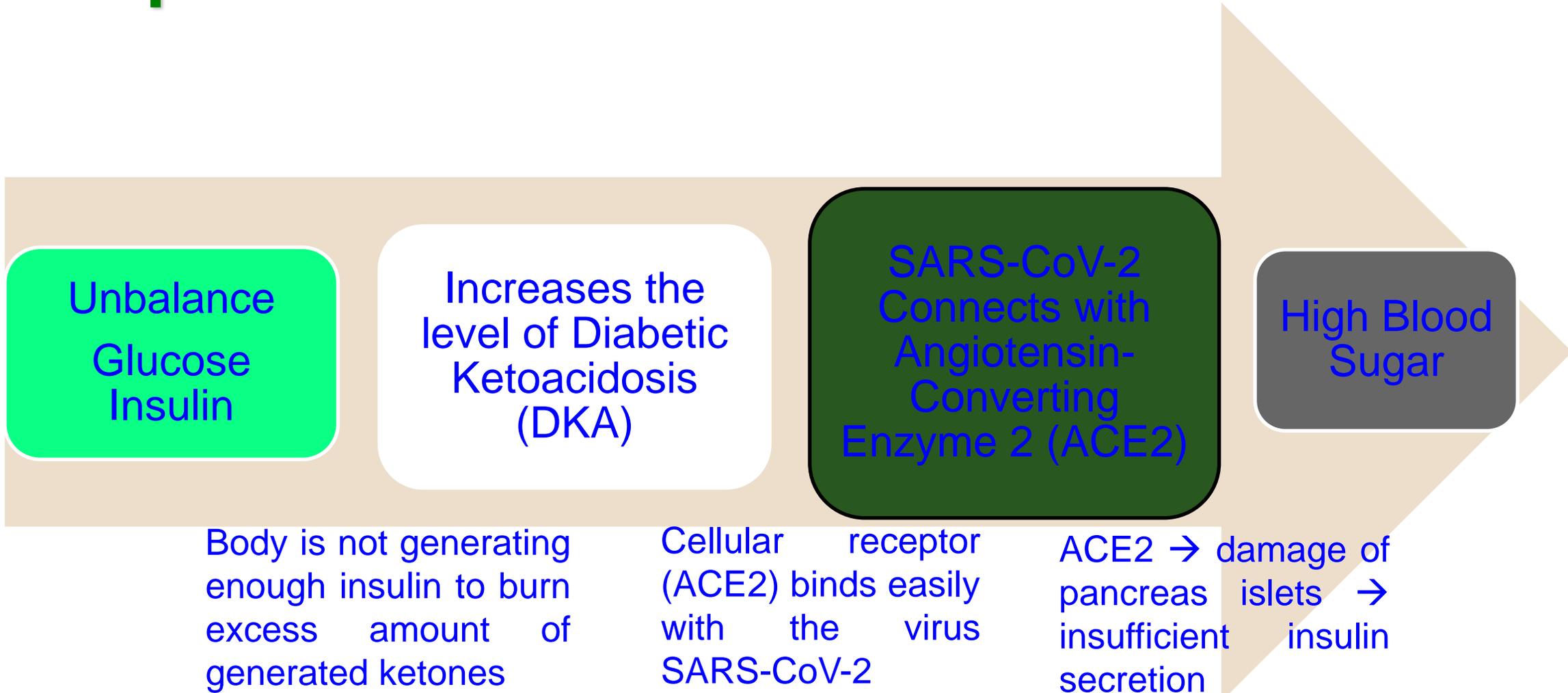
Smart Healthcare – COVID-19 Perspectives

Comorbidities with Pre-existing medical conditions for COVID-19



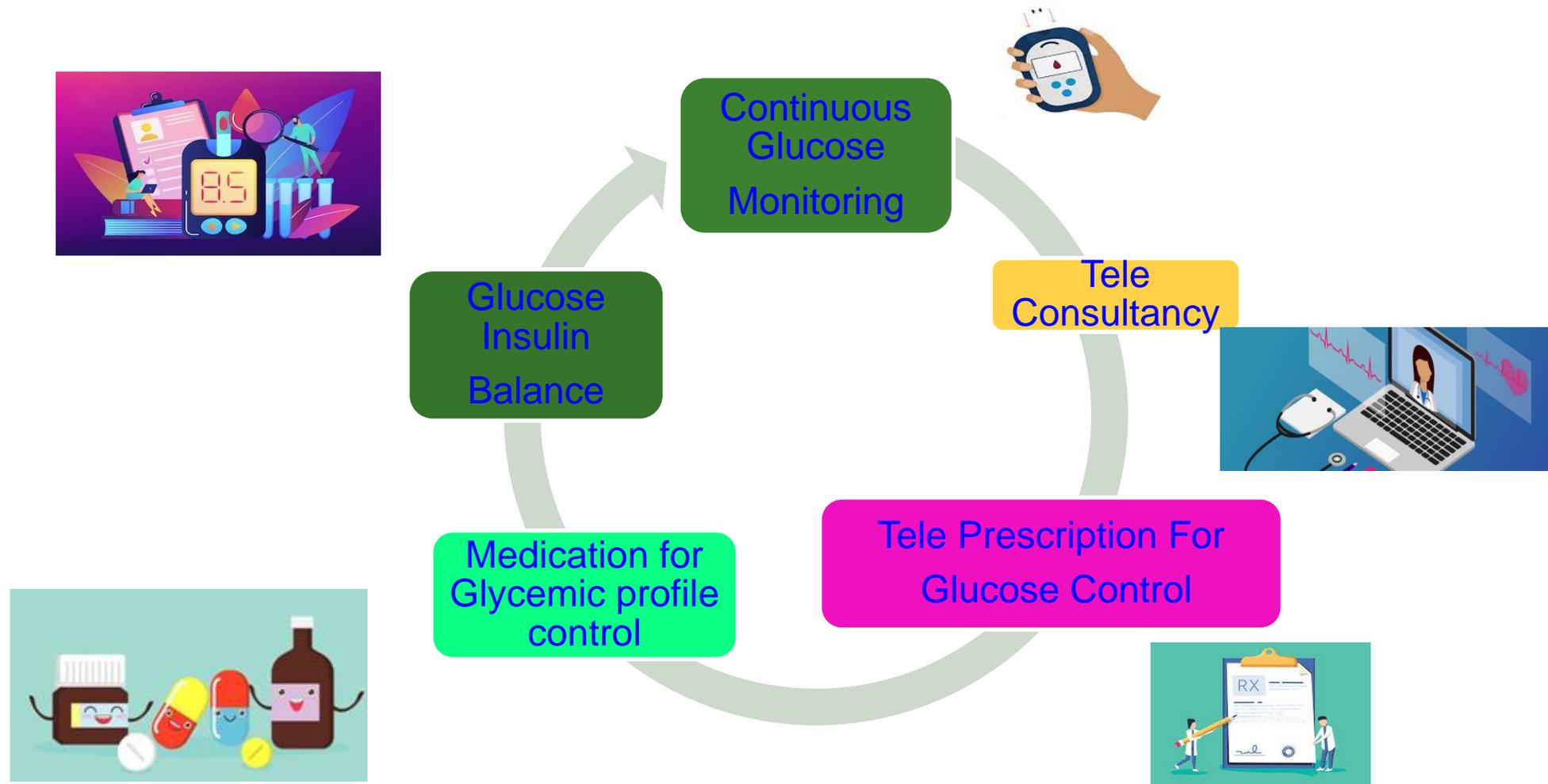
Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

Impact of COVID-19 on Diabetes Patients



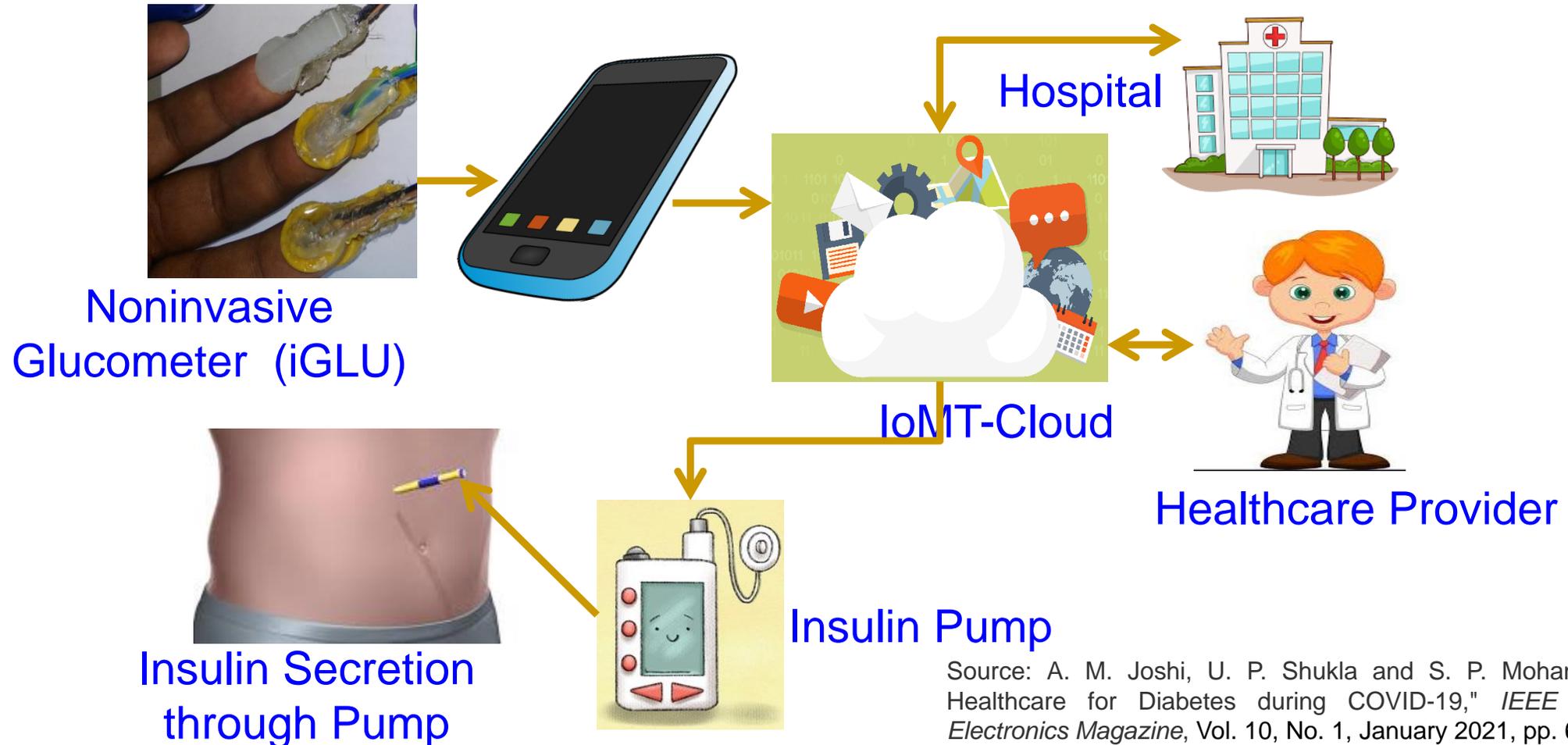
Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

Smart Healthcare in Pandemic – Some Roles



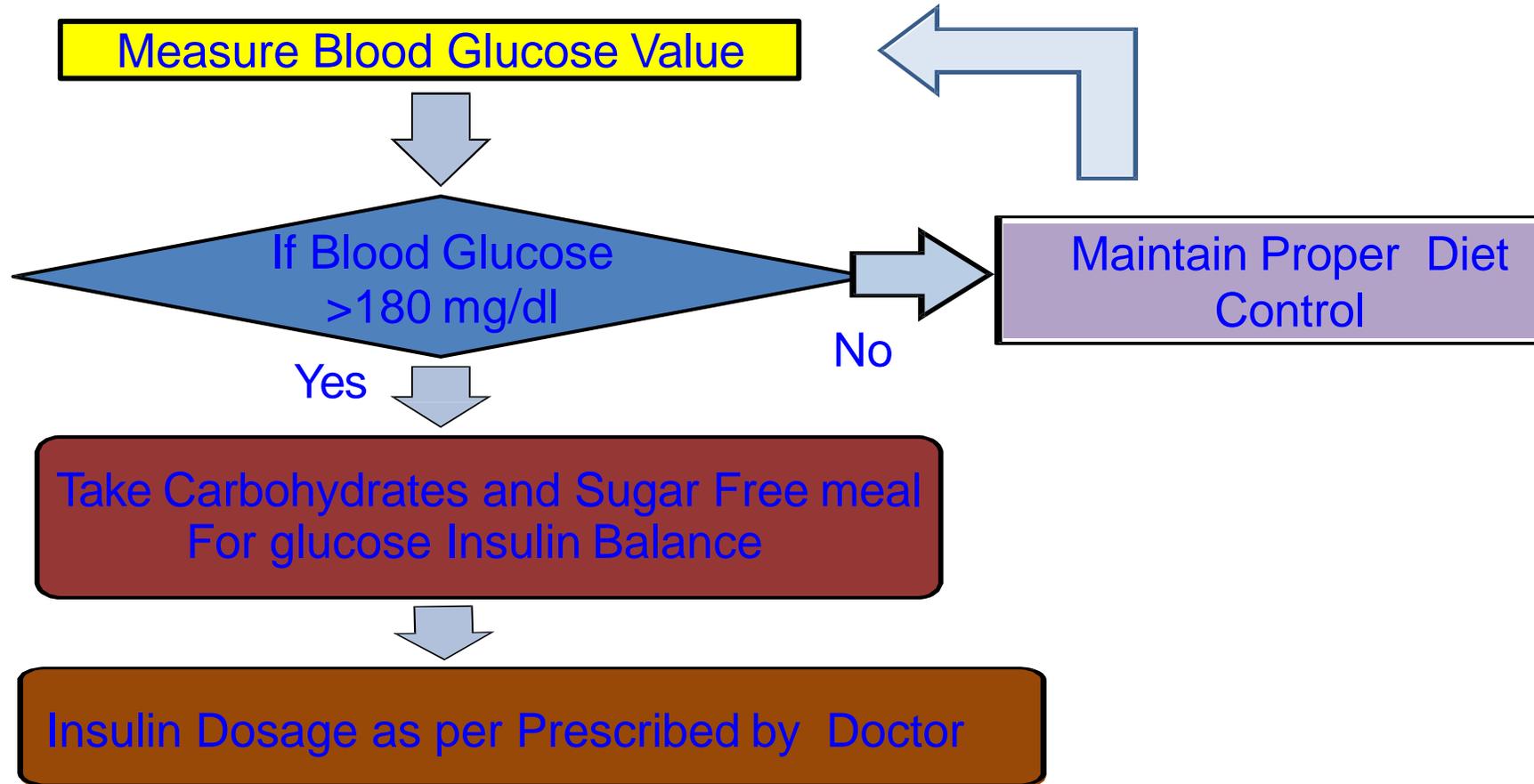
Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

iGLU - Our Intelligent Non-Invasive Glucose Monitoring with Insulin Control Device



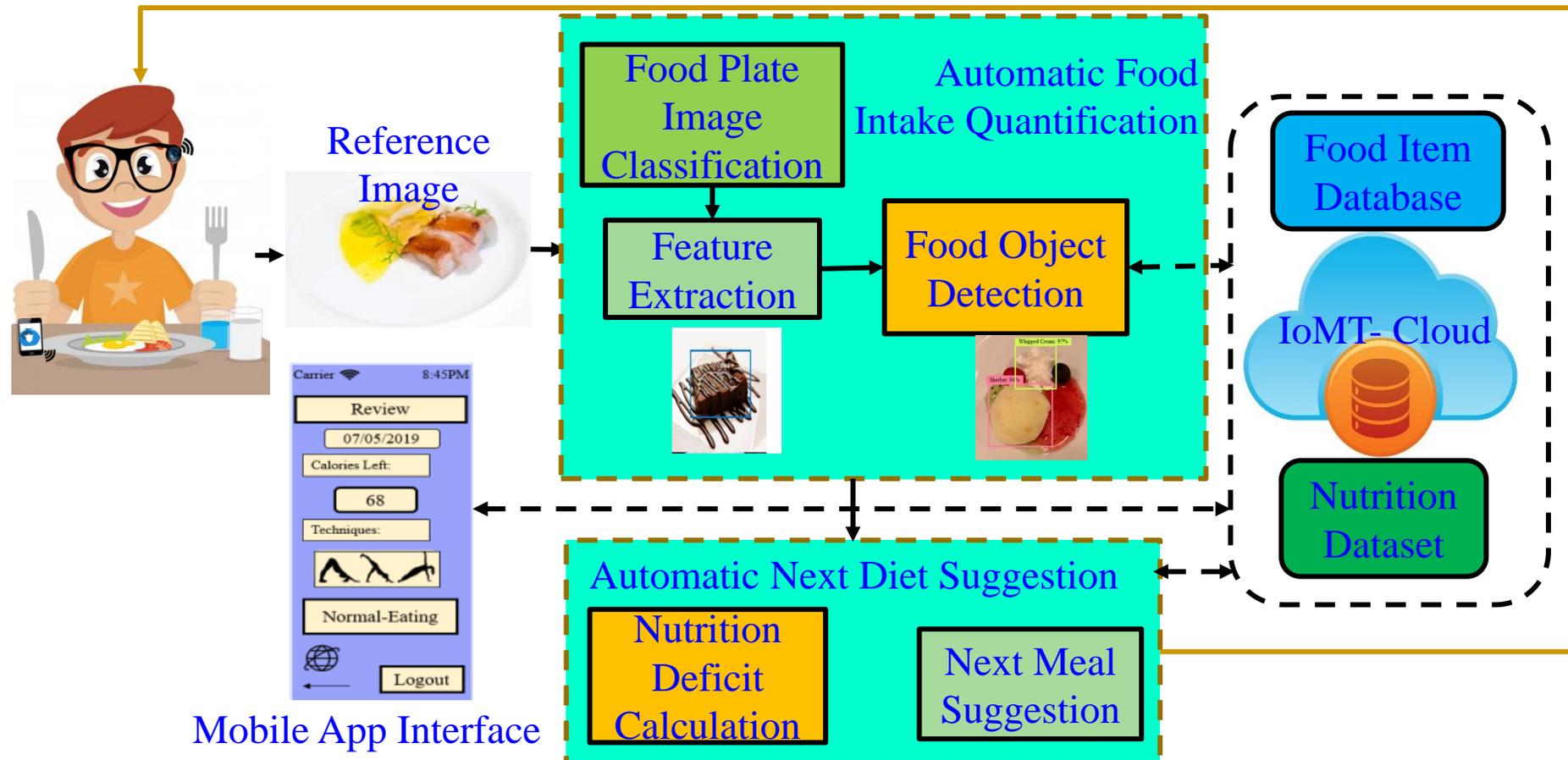
Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

Diet Automatic Monitoring and Control for Blood Glucose Level



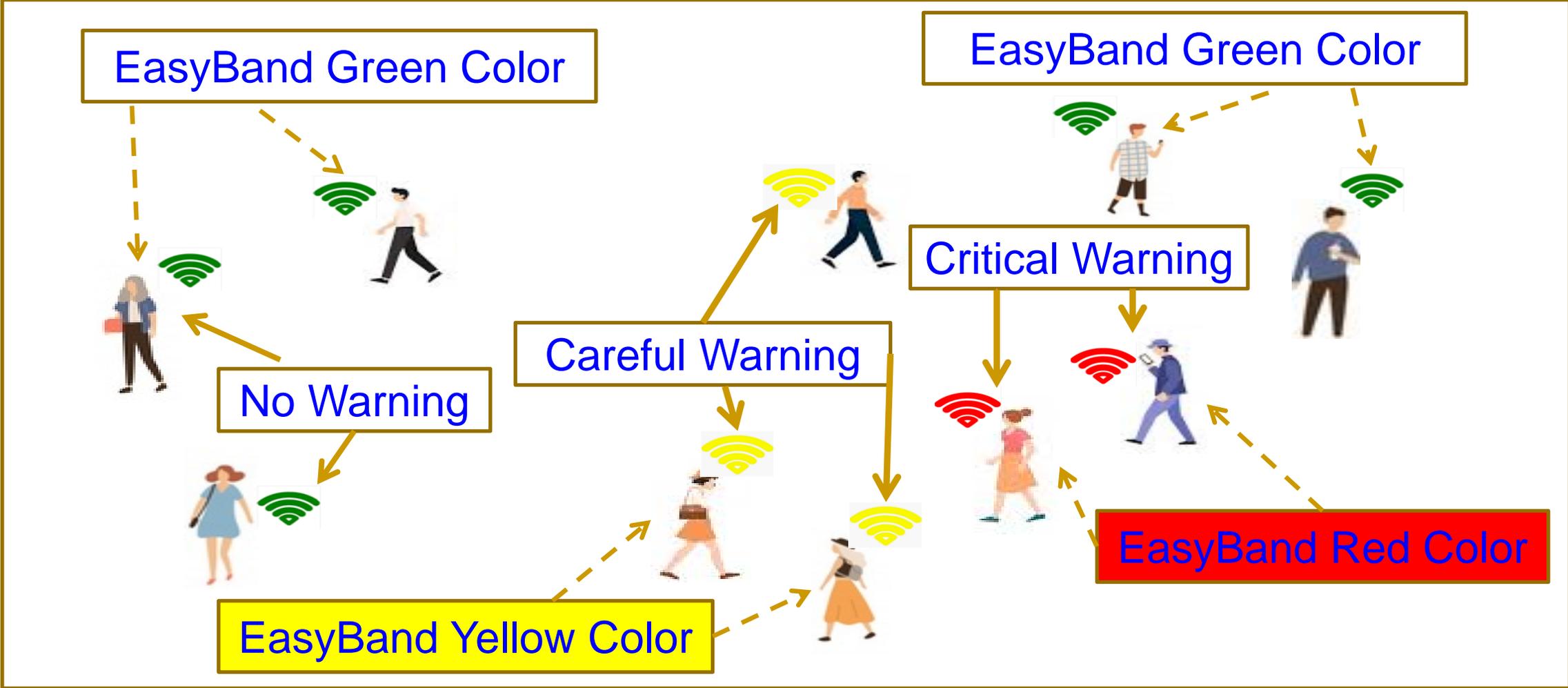
Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

iLog - Our Diet Automatic Monitoring and Control for Blood Glucose Level



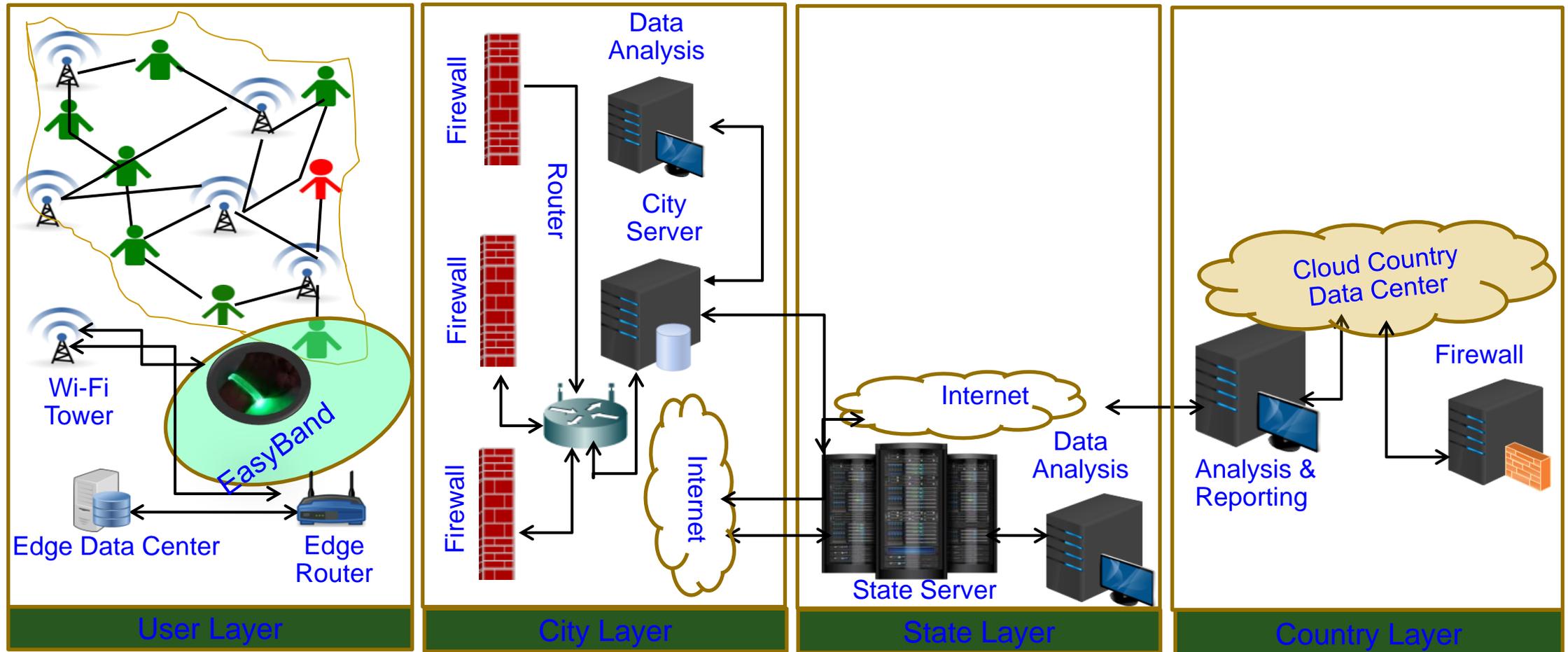
Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

EasyBand – Safety-Aware Mobility during Pandemic



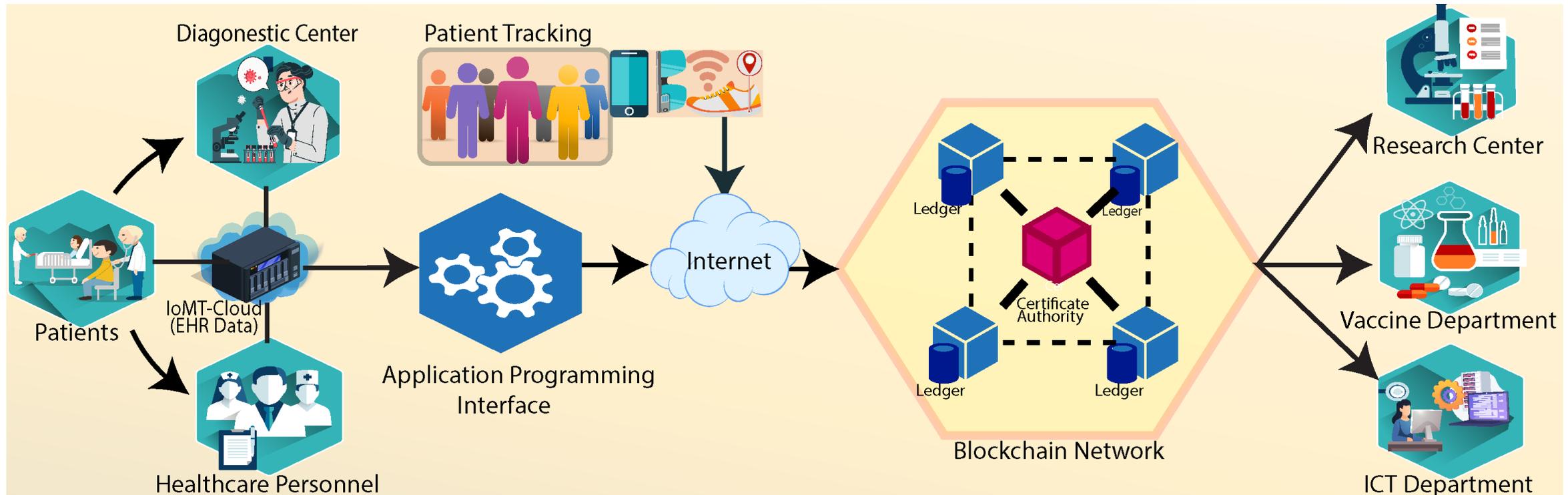
Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

EasyBand in Healthcare CPS (H-CPS)



Source: A. K. Tripathy, A. G. Mohapatra, S. P. Mohanty, E. Kougianos, A. M. Joshi and G. Das, "EasyBand: A Wearable for Safety-Aware Mobility During Pandemic Outbreak," *IEEE Consumer Electronics Magazine*, vol. 9, no. 5, pp. 57-61, 1 Sept. 2020, doi: 10.1109/MCE.2020.2992034..

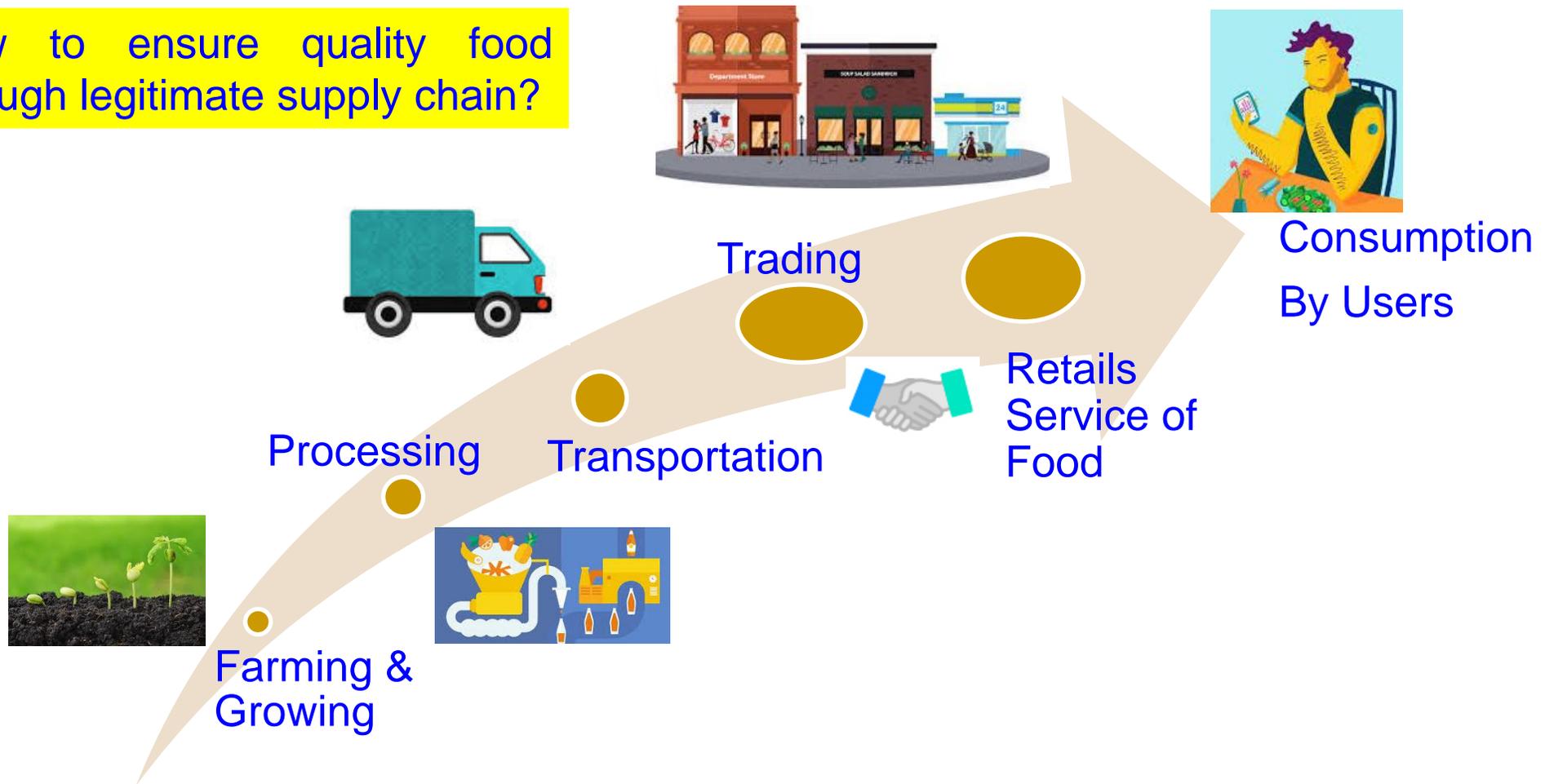
GlobeChain: An Interoperable Blockchain for Global Sharing of Healthcare Data



Source: S. Biswas, F. Li, Z. Latif, K. Sharif, A. K. Bairagi and S. P. Mohanty, "GlobeChain: An Interoperable Blockchain for Global Sharing of Healthcare Data - A COVID-19 Perspective," *IEEE Consumer Electronics Magazine*, doi: 10.1109/MCE.2021.3074688.

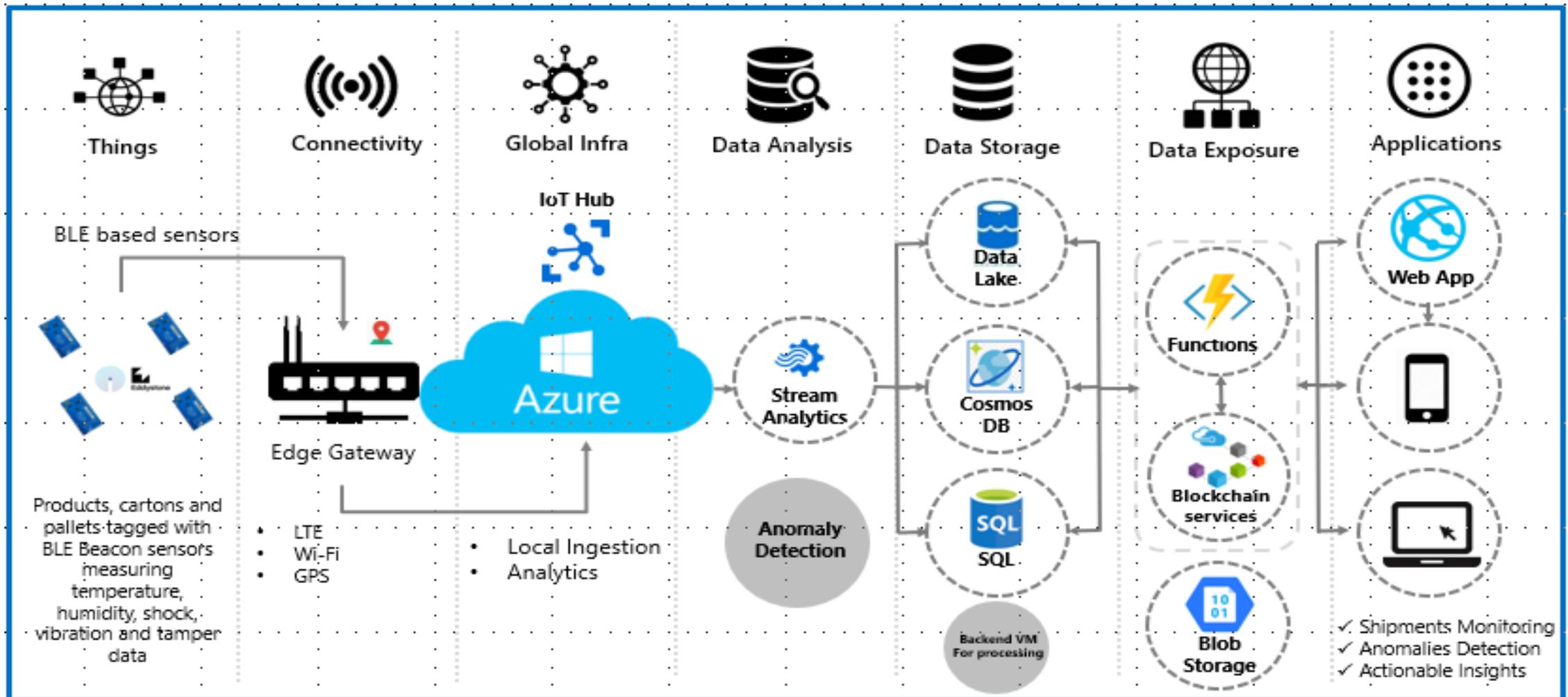
Pandemic – Trusted Food Supply Chain

How to ensure quality food through legitimate supply chain?



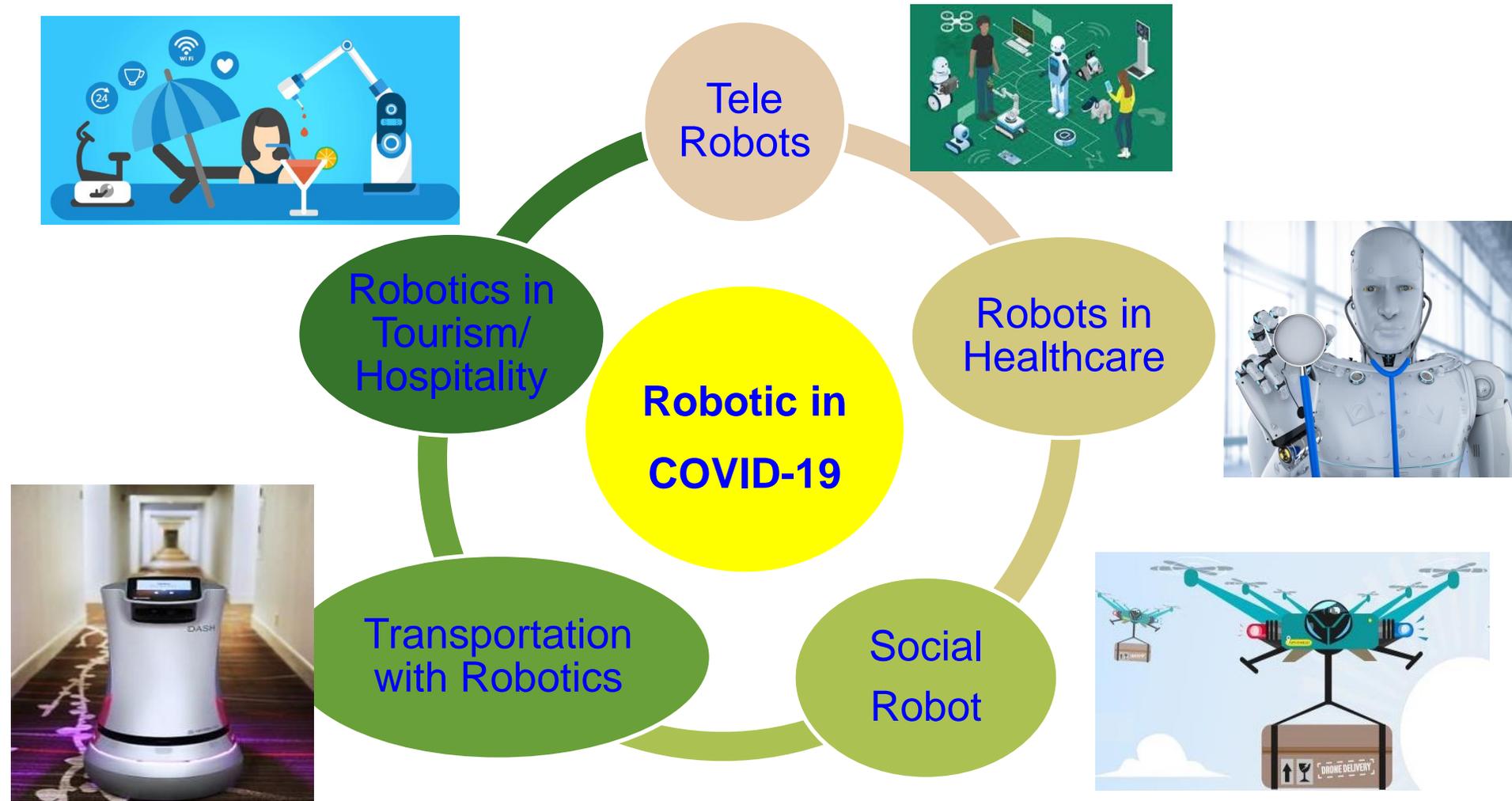
Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

Pandemic – Trusted Pharmaceutical Supply Chain



Source: <http://likesqldata.com/securing-the-pharmaceutical-supply-chain-with-azure-iot/>

Pandemic - Role of Automation



Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

Conclusions and Future Research



Conclusions

- Healthcare has been evolving to Healthcare-Cyber-Physical-System (H-CPS) i.e. smart healthcare.
- Internet of Medical Things (IoMT) plays a key role smart healthcare.
- Smart healthcare can reduce cost of healthcare and give more personalized experience to the individual.
- IoMT provides advantages but also has limitations in terms of security, and privacy.
- Smart Healthcare can be effective during stay-at-home scenario during pandemic.

Future Research

- Machine learning (ML) models for smart healthcare needs research.
- Internet-of-Everything (IoE) with Human as active part as crowdsourcing need research.
- IoE will need robust data, device, and H-CPS security need more research.
- Security of IWMDs needs to have extremely minimal energy overhead to be useful and hence needs research.
- Integration of blockchain for smart healthcare need research due to energy and computational overheads associated with it.
- Privacy-aware limited healthcare data sharing in global scale to reduce spread of pandemic outbreak.

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